BIOLOGY · FOR · TODAY

CURTIS CALDWELL SHERMAN

Man gains control over his biological environment

BIOLOGY FOR TODAY

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PREFACE

The materials of this book are organized on the basis of the energy concept in accordance with the definition of biology given on page 4. The outline and general organization grew out of several years of trial with high-school classes in biology. The learning activities were selected and refined through repeated classroom use. Guidance in the selection of specific topics was secured through extensive research by the authors[1] and other investigators. The topics thus shown to have greatest importance are designated by asterisks. These topics should be included among the minimal essentials in any plan of instruction the biology teacher may use.

The units of work are so organized that they may be used with any coherent plan of instruction. Chapter I serves as an introduction to the entire course. Each of the eight units following Chapter I deals with some fundamentally important aspect of biology in its relation to energy. Each unit is introduced by a preview which presents the major problems discussed in the unit. Each of the chapters composing the unit is introduced by "Questions this Chapter Answers," which provide a more detailed orientation in the unit. Each chapter is divided into minor problems.[2]

Especial emphasis is given to development of the fundamental generalizations of biology and to establishing scientific attitudes

[1] Otis W. Caldwell and Florence Weller, "High School Biology Content as Judged by Thirty College Biologists," *School Science and Mathematics*, Vol. XXXII (April, 1932), pp. 411–424.

Francis D. Curtis, "A Synthesis and Evaluation of Subject-Matter Topics in Biology" (unpublished study). This investigation combines and evaluates, by a technique similar to that used in the investigator's previous study of the subject-matter of general science, the topics revealed in seven investigations of the content of biology and four city and state biology syllabi.

[2] The *Teachers' Manual* includes the outline of a complete unit plan covering one section.

in accordance with the most authoritative recent recommendations.[1] To this end many exercises on fundamental generalizations, scientific attitudes, scientific principles, and scientific method are included in experiments, in legends of illustrations, and in special exercises at the ends of chapters.

The ability of the pupil readily to comprehend a textbook depends chiefly upon two factors: simplicity of vocabulary and clarity of style. One of the authors[2] for several years has conducted research to determine what vocabulary level is appropriate for high-school students of biology. These investigations represent experimentation with several hundred pupils. The results of this study indicate that the difficulty of comprehension of nonscientific words increases greatly in the eighth-thousand "level" of Thorndike's *Teacher's Word Book of 20,000 Words*; also that the seventh-thousand level is difficult as compared with the preceding levels. Consequently the authors have limited the nonscientific vocabulary chiefly to the seven thousand most frequently used words in the English language. When other words are used, each is defined and pronounced, as are also certain words of the seventh-thousand "level" which are not likely to be readily comprehended. Definitions of scientific terms are given in the body of the text and in the Glossary. Defined words are repeated at several points to provide the necessary drill in their use.

Moreover, in order to insure ready understanding by pupils, the completed manuscript was submitted to high-school pupils who were about to begin their study of biology. All passages which any of these pupils found difficult were revised until the reader experiencing the difficulty pronounced the passage entirely clear. The manuscript was also read critically for ease of comprehension by adults who had no special training in biology.

Self-tests on the comprehension of essential subject-matter are

[1] Committee of the National Society for the Study of Education on the Teaching of Science, *The Thirty-first Yearbook of the National Society for the Study of Education*, Part I. Public School Publishing Co., Bloomington, Illinois, 1932.

[2] Francis D. Curtis, "A Study of the Vocabulary Comprehension of Pupils Studying High School Science" (unpublished study).

found at the ends of the units. More extensive tests are provided in the *Tests to accompany Biology for Today.*

Abundant provision for individual differences will be found (1) in special reports offering a wide range in difficulty; (2) in a variety of problems presented in the captions for illustrations and at the ends of chapters [1]; (3) in experiments and projects; and (4) in scientific terms in parentheses at various points in the text and on diagrams (see pages 25 and 52).[2] Many additional experiments and projects are included in the *Workbook to accompany Biology for Today.*

Recognizing the increasing emphasis upon training for the worthy use of leisure as well as upon providing for individual differences, the authors have provided an entire unit (Unit IX) consisting of biological activities for out-of-school hours.

The content of this book has been carefully checked against a large number of representative state and city syllabi and will be found to include the materials required by these syllabi.

THE AUTHORS

[1] These questions, together with the "Self-tests" at the ends of problems and the "Problems" at the ends of chapters are discussed in the *Teachers' Manual.*

[2] These terms are not intended to be considered as minimal essentials to be learned by all members of a class. They are included for the pupils who may wish to learn and to use a more extensive biological vocabulary than that which is here presented as fundamental.

ACKNOWLEDGMENTS

It is impossible to acknowledge individually all who have contributed to a textbook which has been developing in the authors' classrooms during many years. The authors wish, however, to acknowledge their indebtedness to many graduate students and teachers of biology for suggestions, materials, and criticisms. They wish especially to acknowledge the help from those specialists in subject-matter or in science teaching who read the portions of the manuscript dealing with their respective fields: to Professors George R. LaRue and Paul S. Welch, University of Michigan, for constructive criticisms concerned with zoology; to Professor Leon Henri Strong, University of Michigan, for valuable suggestions concerning human anatomy and physiology; to Professors L. W. Keeler and Warren R. Good, University of Michigan, for help with Unit V; to Professor George R. Moore, University of Michigan, for suggestions dealing with dentistry; to Professor Ernst V. Jotter, University of Michigan, for valuable assistance dealing with biological conservation; to Miss Ghissell E. Klein, University of Michigan, Dr. E. E. Dale, Union College, and Dr. Eileen W. Erlanson, Kent State Normal College, for criticism concerned with botany; to Dr. Arthur M. Cramp, Director of the American Medical Association, for suggestions regarding patent medicines; to Dr. A. D. Wickett, Ann Arbor, Michigan, for criticisms regarding physiology, disease, sanitation, and hygiene; to Professor E. W. Sinnott, Columbia University, for reading the chapters dealing with inheritance; to Professor Martin L. Robertson, Colorado State Teachers College, for critical reading of the entire manuscript.

The authors are also grateful to many educational institutions, commercial firms, amateur photographers, and authors of other books for permission to reproduce various photographs and illustrations; to Culver Military Academy for the use of two copyrighted photographs; to the Department of the Interior, Canada, for photographs of the Canadian national parks; to the Fresno, California, Chamber of Commerce and to The Colorado Association for permission to reproduce, respectively, Figs. 1 and 6; to the New York Zoological Society for photographs from the Zoological Park, Figs. 143 and 171.

CONTENTS

Unit IV · *Structures and Processes Concerned with Securing and Using Food Energy*

TO THE STUDENT

Suggestions for Effective Study

Wherever you go you will find living things. Profit and enjoyment may be gained from studying these living things and from your own biological experiments. Cultivate the habit of careful and accurate observation both inside and outside the laboratory. Be always alert to find illustrations and applications of the biological principles and laws to which you will be introduced as this course proceeds. Try to use scientific method and scientific attitudes in the ways these are illustrated in this book.

Until you have gained considerable biological background, you will probably find most of your help from your textbook and your teacher. Here are suggestions for study which many students of biology have found helpful.

Your textbook is organized into a few large units in order to help you in learning to think of biology in terms of its largest ideas and principles. Your problem is somewhat like that of a pioneer in a strange country. He climbs a hill or a tree in order to get a general idea of the surrounding country and to locate the principal landmarks. In the same way you need to get a general idea of the unit and to learn what are its chief problems. Read first "Problems Discussed in this Unit." Recall what you know about these major problems. Turn through the unit, noting the titles of the chapters. Then in the first chapter of the unit read "Questions this Chapter Answers," noting which ones you think you can answer completely, which partly, and which not at all. Turn through the chapter, noting its minor problems. Having gained a good general idea of what the unit discusses and the problems of the first chapter, you are now ready to take up the study of the day's assignment. The remaining chapters of the unit should be attacked in the same way. You will find the study methods given in the following pages helpful.

1. First read the entire assignment through rapidly. Then, with its main points in mind, read the assignment again carefully, paragraph by paragraph, for a more accurate and detailed knowledge of what it contains. Train yourself to get the essential ideas and facts out of each paragraph with only this second reading. There should be little or no difference between reading a text and studying it.

2. Each chapter of this book is composed of sections of one or more paragraphs which deal with the topic that is suggested in the section title. In your second reading, read carefully, then close the book and try to state the most important ideas in the paragraph or paragraphs you have just read. It is not desirable to try to remember or to repeat the exact words of the book. It is far better to remember the ideas which the passage presents and to restate these in your own words. At first you may not be able to do this with a single careful reading, though you should try to make one reading serve. It will be possible soon to train yourself to master a short section in a single careful reading.

3. As you read a paragraph try to find a key sentence, that is, one sentence which indicates better than any other in that paragraph what the whole paragraph is about. Often this sentence will be the first one in the paragraph. For example, the key sentence in the first paragraph of Chapter I is the first sentence, "Biology is the oldest of all branches of learning." Sometimes the key sentence is the last one, as, for example, "Therefore all the food in the world may be traced finally to the sun" (p. 5). *If the book is your own,* it is good practice to draw a line under each key sentence. Having them thus marked will be of great help to you both in fixing the idea in mind and later in reviewing the materials.

4. After you have read a paragraph, close your book and try to make a summary of the most important thought of the paragraph in a single sentence. Of course the length of this sentence will vary with the material and length of the paragraph, but twenty words is a convenient limit to set yourself. For example, the paragraph beginning with "What is the source of this energy?" (p. 5) can be summarized by this sentence, "All plants and animals depend on the activity of green plants in transforming the sun's energy into food energy."

If the book belongs to you, it is good practice for you to write in the margin, beside the paragraph, your sentence summary of it. As in underlining, this practice will help you to remember the important thought, and will also help in reviewing.

5. After you have read a paragraph, write a few questions the answers to which you think are important and which you think any student who has read the same paragraph should be able to answer. Try to make these questions test the application of facts rather than the mere recall of the facts themselves. Here are two good questions which require not a mere knowledge of facts but an application of them: "Why may we say that a fish gets its food from the sun?" (Page 7.) "Could a whale live in an ocean where there are no plants? Explain." (Page 7.) Under the illustrations and at the ends of the chapters are about forty different kinds of questions. Try to make a number of different kinds of clear, meaningful questions which are real tests of what one should learn from his reading.

6. Always study an illustration at the point where it is referred to in the text. Only in this way can you get the most benefit from the illustrations. Additional facts or questions are included in most of the legends under the illustrations. Try to answer these questions.

7. Few students are able to give a good discussion of a topic. Too often when asked to discuss, the student merely tells everything he can remember about the topic, giving the facts in a disconnected way as they occur to him. You can train yourself to make good discussions by learning to follow this simple outline of questions, answering each as you come to it:

What is it? (State with a definition or a short description of the object or process you are discussing.)
What is its history (if its history is important)?
What is its habitat; that is, where is it found? Or where does it occur?
What are its most important characteristics,— those which distinguish it from everything else?
What can it do?
What is its relation, if any, to man?

Not every topic, of course, will entirely fit this outline. Omit the questions which are not appropriate.

8. Comparing one animal, plant, process, or law with another is a valuable way of learning and remembering important facts and principles. A good comparison includes both those respects in which things are alike and those respects in which they are different. Therefore write first all the similar characteristics of the two organisms, biological processes, or whatever you are comparing. In a separate column write all the respects in which they are different. Then select from the two columns the points which you think are of most importance.

9. The successful student usually reviews his material frequently and thoroughly. At the ends of the problems within the chapters are tests which will aid you not only in testing yourself to see whether you have mastered the materials but also in reviewing the materials. *Do not write the answers to the test questions in your book,* since such practice will rob them of most of their value for later reviews, when you will want to test your memory and re-read parts which you have forgotten.

10. After you have completed the study of a chapter, turn again to "Questions this Chapter Answers." If you cannot now answer all these questions, review the chapter until you can. After you have completed the study of any unit, turn back to the introduction to the unit. Re-read it. Change each of the large unit problems into a complete statement. Then, using these statements as major headings, write under each, in your notebook or in the Workbook at the place indicated, complete statements which further explain or give proof of each problem presented. You may be able also to organize the problems and your statements in the form of an outline.

11. In making a comparison or a discussion, in reviewing, or in summarizing a unit, use any knowledge or experience you have had, whether gained in school or out of school.

BIOLOGY FOR TODAY

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Fig. 1. The General Sherman sequoia, in Sequoia National Park, California, has been living throughout most of human history. It was a sturdy young tree at the time the pyramids were built; today it is the largest living thing. It is estimated to be more than four thousand years old. About what fraction of its life is represented by all the time since Columbus's first voyage to America?

Chapter I · Biology Deals with All Living Things

Biology then and now. Biology is the oldest of all branches of learning. Thousands of years before anybody ever thought of algebra, history, or English, primitive man was studying the nature of his environment. He did so because his life depended upon accurate knowledge of the living things about him. He had to observe and study the habits of the animals in order to know which were harmless, which he could capture or successfully fight, and which he must avoid because they might harm or even kill him. He had to know which fruits, leaves, and roots he could eat, and which were unpalatable[1] or poisonous. This knowledge was biology of a crude and practical sort; yet it was probably the chief knowledge that the most ancient men needed to have.

When the Western pioneers, of whose rugged courage we are justly proud, went to make new homes in the wilderness, they carried with them many different kinds of knowledge. The most important and useful knowledge which they had, and the knowledge which they most often used, doubtless had to do with the habits of animals and the natures and uses of trees and other plants. This was biological knowledge.

What a contrast between primitive man peering fearfully from his refuge in a cave or in a tree upon a hostile and dangerous world, or even between the sturdy settler (see frontispiece) risking his security and success upon his understanding of the wild life about him, and a present-day biologist in the comfort and safety of his modern laboratory, observing through his powerful microscope a world of living things unknown a few centuries ago! Yet a knowledge of biology and the use of that knowledge are as necessary to successful living now as they have ever been. Moreover, as our ways of civilized living become more complex, there is an increasing need for a broader and deeper knowledge of biology.

[1] *Unpalatable* (un pal′at a bl): not palatable, that is, not pleasing to the taste. *Un*, *dis*, *non*, or often *in* at the beginning of a word gives the word the opposite meaning from the one it would have without that syllable.

Biology and living things. Biology deals with all living things. The word *biology* is derived from two ancient Greek words which together mean "the science of life."

When we consider that biology deals with all animals and all plants of whatever kinds they may be, we realize at once what an extensive study biology is. There are more than a million different kinds of animals and plants now living, and these differ from one another greatly and in many ways. For example, the largest living things, though not the tallest or oldest ones now on the earth, are the sequoia trees in Sequoia National Park, California. Certain seaweeds, the longest plants known, may reach six hundred feet in length. The smallest living things cannot be seen, even with the most powerful microscopes yet invented. The oldest living things are trees (Fig. 1). The baobab trees of Cape Verde are believed to be more than five thousand years old, and certain cypress trees of Mexico are perhaps still older. Some of the simplest plants, however, live their entire lives during less than an hour.

All the animals and plants now living, moreover, are but a small part of all those which have lived since the time, millions of years ago, when life first began on the earth. Countless kinds of plants and animals, many of them similar to those now found on the earth and others quite different, existed for a while and then became extinct. But all animals and plants that ever have lived on the earth have faced exactly the same problem. They have had to be able somehow to secure energy in the form of food and to use it in such ways as to make life possible. If an individual animal or plant failed to do this, it died. If all the individuals of its kind failed to do this, the kind died out and became extinct (Fig. 2).[1]

What is biology? Biology may be defined as the study of the ways in which plants and animals secure, conserve, and use energy. You have probably learned in your previous work in science that energy is the capacity to do work, that is, to move or to cause some other object to move (Fig. 3). All living things are constantly using energy. They are constantly transforming or changing food energy into heat and the energy of movement. A few animals and plants, such as glowworms and certain fungi,

[1] To THE TEACHER. Suggestions which may be of value in the use of illustrations will be found in the *Teachers' Manual* to accompany this textbook.

A Century of Progress

Fig. 2. These huge reptiles and these plants lived millions of years ago, but they and their kind have long since vanished from the earth. How many reasons can you give which might explain their disappearance?

transform food energy into light energy. A few tropical fish, as the electric eel, transform food energy into electrical energy.

What is the source of this energy? The sun is about ninety-three million miles from the earth. It is constantly radiating light, heat, and other forms of energy in every direction. Of this energy the earth receives only a very small fraction — about one part in every two billion. Without this small fraction of the sun's radiant energy, however, no life of any sort would be possible on the earth. Plants and animals cannot live on this radiant energy just as it comes from the sun. It must be transformed, or changed, into food energy. Men and other animals cannot make their own food from the sun's energy. They must find it already made. They must secure and eat other animals or plants or their products. Green plants, however, can use the radiant energy of the sun to manufacture their own food. Thus every green plant is a food factory. All the food in the world which all the plants and animals consume in order to secure the energy they need was made by green plants. Therefore all the food in the world may be traced finally to the sun.[1]

[1] It is true that some of the radiant energy from other stars than our sun reaches the earth, but this starshine is so faint as not to be considered as a source of radiant energy on the earth. It is true also that some of the simplest organisms use certain elements and certain simple compounds which are not made by green plants, but these exceptions to the general statement are few.

Fig. 3. How many examples of different things which possess energy can you see in these pictures?

If the contents of the stomach of a whale, the largest animal, were examined it would be found to contain fishes. If the stomachs of these fishes were studied, they would be found to contain smaller fishes or other aquatic[1] animals. If those in their turn were studied in the same way, they would be found to contain still smaller aquatic animals or plants. Finally we should discover that the smaller animals had been feeding upon miscroscopic animals and plants that are found in countless numbers and varieties in fresh water and near the surface of the oceans. All these plants have chlorophyll[2] and hence can manufacture their own food by changing the radiant energy of the sun into food energy. Hence we may say that the whale gets its food indirectly from the sun.

Suppose we eat a piece of beefsteak as a source of our needed energy. The animal from which the steak was obtained got its energy from eating green plants or their seeds. These plants transformed the sun's radiant energy into food energy through the aid of their chlorophyll. Hence we may say again that we get our beefsteak indirectly from the sun.

And so it is with everything we or any other living creatures eat. Food energy may finally be traced to the radiant energy of the sun, transformed by green plants into food. Biology[3] therefore deals with the constant struggle of all living things for energy (Fig. 4).

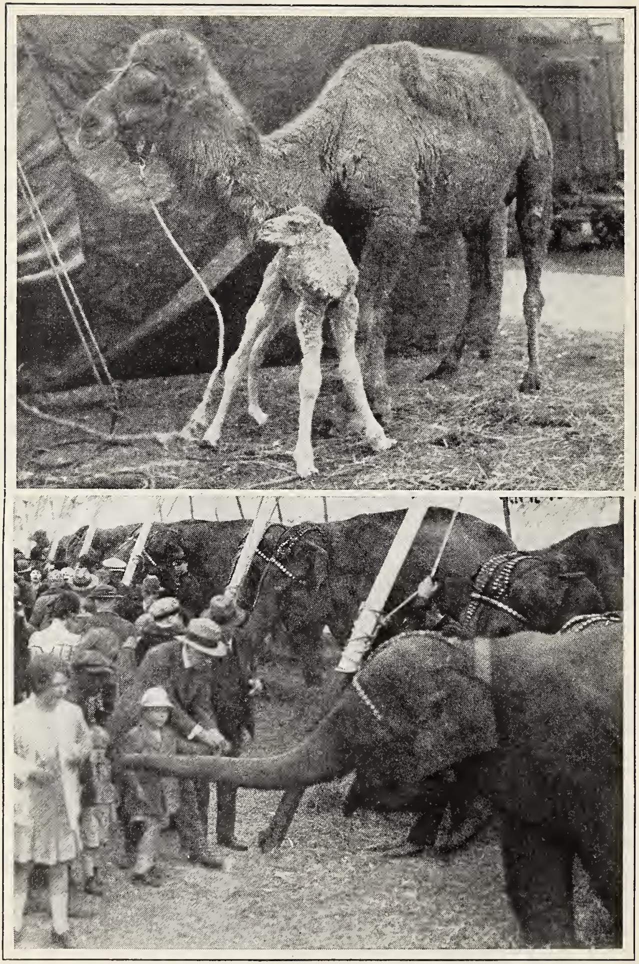
Of what use is biology? The apple is one of the earliest known fruits. Two varieties of apples were known to the people of the Stone Age. There are now several hundred varieties. All these

[1] *Aquatic* (a kwat'ik): living in the water or upon its surface.

[2] *Chlorophyll* (klo'ro fil): the green material in plants.

[3] There are many divisions of biological study, for example:

Botany, study of plants.
Zoology, study of animals.
Physiology, study of the life processes, such as digestion, food-getting, and the like, of plants and animals.
Ecology, study of the relations of plants and animals to their environment.
Morphology, study of the forms and parts of plants and animals.
Anatomy, study of the details of tissues of plants and animals.
Cytology, study of the details of cells and protoplasm.
Embryology, study of the early stages in the development of plants and animals.
Pathology, study of plant and animal diseases.
Bacteriology, study of bacteria, how they live and how they affect other things.
Paleontology, study of fossil records of plants and animals.
Genetics, study of the heredity of plants and animals.
Taxonomy, study of the names and classification of plants and animals.



Newton H. Hartman and H. A. Atwell Studio

Fig. 4. In what sense are these animals engaged in "the constant struggle for energy"? What biological problems which are now solved for them would these animals need to solve if they were wild?

FIG. 5. What biological problems are suggested in this picture?

were developed from a species of wild apple tree with fruit less than an inch in diameter, which is still found growing wild over central and southern Europe. All the improved fruits and vegetables which are so important a part of our food were developed from less desirable fruits and plants. The science of producing improved varieties of plants and animals is one part of applied biology.

Skulls of ancient men have been found from which circular pieces of the bone had been removed with crude stone tools while the owners of the skulls lived. These operations were performed in the effort, it is believed, to cure illnesses. In some cases the operation was performed five times upon the same person, yet he died later of some cause other than the operations. Medicine has made giant strides since these crude attempts at surgery.[1] All that is now known in this field is applied biology.

[1] *Surgery* (sur′jer y): the branch of medicine which includes removing or changing diseased parts.

Pennington

Fig. 6. Pine River, Colorado. What knowledge of biology is necessary to the man who is fishing? What knowledge of biology do you use every day? Can you name at least ten callings or activities which demand some accurate knowledge of biology?

The development of cities has produced many new biological problems (Fig. 5). Many of these have been solved through the applications of science. For example, until fairly recent times, cities had no satisfactory ways of disposing of sewage and garbage. Some ancient cities were buried in their own refuse and by dust and sand, and new cities were built upon the tops of older ones. The science of sanitation, which makes our modern cities and dwellings clean and healthful places in which to live, is merely applied biology. And so we could go on describing countless applications of biology and still we should not have answered completely the question "Of what use is biology?" (Fig. 6).

Biological materials may be found almost everywhere. They are constantly to be found both inside and outside of our homes. In a vacant lot one may find among the weeds various animals such as grasshoppers, crickets, beetles, perhaps a garter snake, a toad, seeds and fruits of plants, and many things to take to the school laboratory for further observation and study or to put into collections in a "biological museum."

Biological principles and scientific attitudes. The proper use of biology includes the development of scientific attitudes and the application of principles of biology. A list of scientific attitudes should include those on pages 12 and 13.

In the problems studied in biology there is abundant opportunity to apply these attitudes and to master the important principles which will be developed in the following units of study. There will also be exercises in applying the methods used by scientists.

Exercise on Scientific Attitudes. Which of these attitudes were used by primitive men, discussed at the beginning of this chapter? Which of the attitudes tend to prevent (1) gossip; (2) slander; (3) belief in advertising claims in general; (4) belief that everything that is printed is true; (5) wearing "good-luck rings" for good luck; (6) belief in ghost stories?

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Scene in the Great Smoky Mountains National Park. Can you state several biological problems which are suggested in this picture? Are any of the problems similar to those suggested in Fig. 5, p. 9? in Fig. 6, p. 10?

Scientific Attitudes

1

A scientist believes that nothing can happen without a cause.

2

A scientist does not believe in superstitions, such as charms or "signs" of good or bad "luck."

3

A scientist believes that occurrences which seem strange and mysterious can always be explained finally by natural causes.

4

A scientist believes that truth never changes, but that our ideas of what is true change as we gain more and more knowledge.

5

A scientist is slow to accept as facts any statements that are not supported by convincing proof.

6

A scientist does not believe that there is necessarily any connection between two events just because they occur at the same time (as in a coincidence).

7

A scientist is curious to know about his environment.

8

A scientist tries to be careful and accurate in all his observations.

9

A scientist prefers, when possible, to do his own observing and experimenting. When it will help, he does not hesitate to use the results of other people's observations, if the evidence is good and if he knows that these others are scientists of established reputation.

10

A scientist patiently collects his facts by making his observations over as long a period of time as is necessary to solve his problem.

11

A scientist never bases final conclusions upon one or a few observations.

12

A scientist continues to hunt for satisfactory explanations of the phenomena he observes until he is convinced that he has found an explanation as nearly correct as the evidence permits. He is willing to change his conclusion if later evidence shows that his first conclusion is wrong.

13

A scientist does not express opinions or announce conclusions until he has considered the matter from all sides.

14

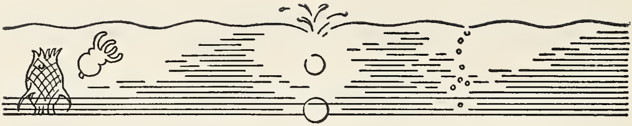
A scientist does not begin to experiment blindly and carelessly. He carefully plans to do his work in what seems, after careful thought, to be the best way.

15

A scientist considers for himself the evidence he hears and the facts he learns, and tries to decide whether they really relate to the matter which is being considered, whether they are sound and sensible, and whether they are complete enough to allow a conclusion to be made.

16

A scientist respects another's point of view. He is willing to be convinced by evidence. In other words, he would say: "I may be wrong in my beliefs, opinions, or conclusions. I will not change these without convincing evidence, but I shall always be willing to change if somebody shows me proof that I am wrong."



IF, RETAINING SENSE AND SIGHT, we could shrink into living atoms and plunge under water, of what a world of wonders should we then form part! We should find this fairy kingdom peopled with the strangest creatures: creatures that swim with their hair, and have ruby eyes blazing deep in their necks, with telescopic limbs that now are withdrawn wholly within their bodies and now stretched out to many times their own length. Here are some riding at anchor, moored by delicate threads spun out from their toes, and there are others flashing by in glass armour, bristling with sharp spikes or ornamented with bosses and flowing curves; while, fastened to a green stem, is an animal convolvulus that by some invisible power draws a never-ceasing stream of victims into its gaping cup, and tears them to death with hooked jaws deep down within its body.

HUDSON and GOSSE, *The Rotifera* (1886)

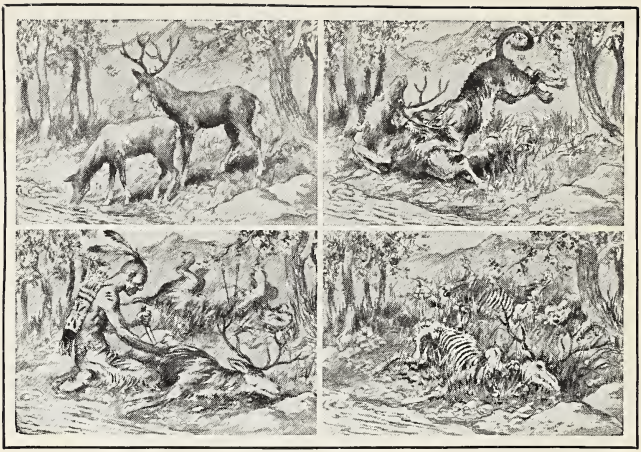
UNIT I · *Some Problems which Living Things must Solve in Securing and Using Energy*

PROBLEMS DISCUSSED IN THIS UNIT

Have you ever observed the battles which are constantly being fought on every lawn, in every weed patch, meadow, or forest? Day and night, every day of the year, the warfare goes on. Some of the enemies are living; some are not. Who or what are fighting? What is the cause of the warfare? How is the warfare carried on? What are the rewards of victory and the price of defeat?

Chapter I introduced the course in biology by stating what biology is and with what it deals. It defined biology as "the study of the ways in which plants and animals secure, conserve, and use energy." This unit explains some further relations of biology to energy. It gives answers to such major problems as the following:

How are living things engaged in the struggle for energy?
What is man's part in the struggle for energy?
How are living things dependent upon their environment?
What characteristics distinguish living things from nonliving things?
Of what importance to living things are such processes as oxidation and osmosis.



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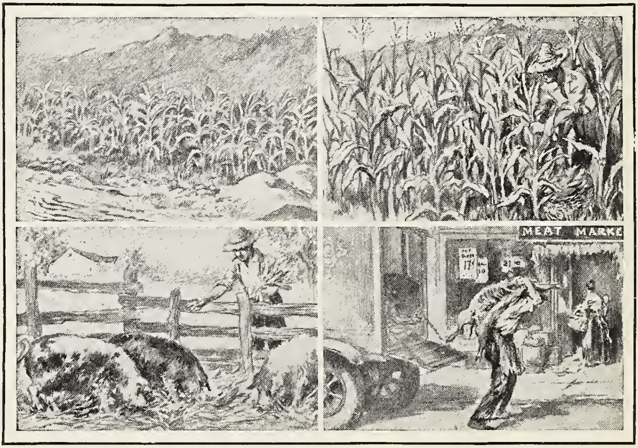

Today

Fig. 7. Self-test on Biological Principles: Define or explain in your own words *energy cycle* and *matter cycle*. Explain how this series of drawings illustrates both

Chapter II · The Struggle for Energy

Questions this Chapter Answers

What is the energy cycle? the matter cycle?
What are independent and dependent plants?
Why do most animals and plants need to be complex?
What is meant by "division of labor"? What is its importance?
How do plants and animals compete with one another for energy?
What are some means of protection which animals and plants possess?
What is meant by "the balance of nature"?
In what ways does man upset the balance of nature?

Problem II–A · How are Living Things Engaged in the Struggle for Energy?

*[1] **Energy, matter, and life.** Each kind of plant or animal strives to keep alive as long as possible and to thrive during its life as much as possible. To do this it must be able to secure food, because food contains not only fresh supplies of energy but also fresh supplies of materials with which to grow and to rebuild or replace injured and worn-out parts of its body. New energy which living things can use cannot be created. Energy can only be changed from one form to another. Thus the green plant does not make new energy when it makes food. It merely transforms the sun's light energy and heat energy into another form, food, which it can use. In its own activities the living green plant is constantly transforming food energy into heat energy, chemical energy, and mechanical energy, that is, the energy of movement. When it dies or becomes a prey to other creatures, this energy which it possessed is again transformed, and is passed on and on from one plant or animal to another endlessly. But the energy is

[1] To the Teacher. The paragraphs marked with an asterisk contain the materials which extensive research has indicated as being of major importance (see Preface). Suggestions for effective use of this material will be found in the *Teachers' Manual.*

never destroyed. This constant transforming of one form of energy into another and from one living thing to another is called the *energy cycle.*

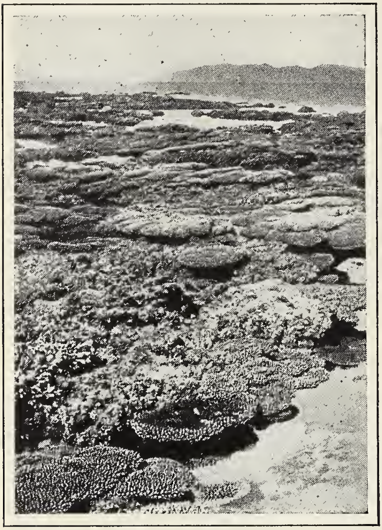

Fig. 8. The Great Barrier Reef, Australia. The new coral animals build their tiny shells upon older shells until, in the course of centuries, the coral reef reaches the surface of the ocean.

Self-test on Biological Principles: Explain how these facts illustrate the principle "All living things die, but life continues from age to age"

*It is the same with matter as with energy. There is only a given amount of matter available. No new matter can be made. No matter can be destroyed. It can only be changed (Fig. 7). Thus when an animal or plant carries on any of its life activities, it must take the matter it needs from the common store in the form of building materials for growth, replacement, and reproduction. If the available building materials become reduced, the number of living things must be reduced. Should the building materials become entirely exhausted, no new animals or plants could begin life. And the living animals and plants would die almost at once, because too much of the needed matter for growth and for the replacement of worn-out parts would be in the bodies of the animals and plants already living. Death, therefore, is necessary to continued life, because whenever a plant or an animal dies, not only its store of energy but also its matter is again made available to be used over and over by other animals and plants. Thus while every individual animal or plant lives only a relatively short time, life itself continues from age to age (Fig. 8).

***Independent and dependent plants and animals.** Living things may be classed as either independent or dependent, as determined by whether they are able to make their own food or must find it already made. Thus only the green plants are independent. Only they of all the living things are able to manufacture their own food with the aid of the sun's energy. There are a few green plants, such as the mistletoe (Fig. 9) and dodder, which are dependent because they can make only part of the food they need. These plants must live as parasites. A *parasite* is any living thing, plant or animal, which lives inside or upon, but always at the expense of, some other living organism. All plants which are not green — for example, the mushroom — are dependent because they do not possess any chlorophyll with which to make their food. Such plants are either parasites or saprophytes. A *saprophyte*[1] is a plant that secures its food from the bodies of dead plants and animals. Unlike a parasite, it never attacks living things. All animals are dependent because they must always secure their food energy by preying upon other animals or plants or by eating animals and plants which have otherwise been killed or have died. Some animals, like some of the plants, are parasites. Parasites and saprophytes will be discussed at many points in later chapters.

FIG. 9. The mistletoe is a parasite on the oak and some other trees. Can you name any other plant parasites?

Most living things are complex. To be able to secure their shares of the limited stores of energy and matter, most living things need to be complex. A brief study of some typical living things will illustrate some of the respects in which they are not simple and why they need to be complex. Let us examine first a living seed plant. Any plant will do, for we shall study now only

[1] Consult the Glossary for the pronunciation of scientific terms.

Fig. 10. How does the dandelion plant illustrate division of labor?

general characteristics. We shall go more into detail later. A dandelion plant can usually be found for such a study (Fig. 10). The whole plant has four main parts: the roots, the stem (which may be difficult to distinguish from the root), the leaves, and the flowers. Each of these parts is necessary to the existence of a typical flowering plant. It must have roots in order to remain anchored. These roots must be deep enough and strong enough to prevent the plant from being pushed over or pulled out of the ground by the wind or by animals. These roots must be sufficient in number and must extend sufficiently far to secure from the soil supplies of water and some of the necessary matter which the plant uses as building materials for growth and replacement of worn-out parts. The stem of the dandelion is very short; but, like the stems of other seed plants, it must be long enough and of the right sort to hold its leaves up to the sun's radiant energy. The plant must have leaves for its food manufacture. The bigger it grows the more leaves it must have to provide the necessary food for its own growth and for storage in its seeds and roots.

Finally the dandelion, like every other seed plant, has flowers. This particular plant which we are examining could have lived its life without flowers. They are not necessary for its own existence. But without flowers it could not produce seeds and hence could not produce new dandelion plants. Without reproduction its kind would soon die out.

***Special parts and special work.** The dandelion, then, is a complex being and needs to be complex. Every part has a certain

definite and important service to render to the plant as a whole. Each part is sized, shaped, and constructed so as to be able to do its special work. Usually any one part does only its own work, because other parts of the plant will perform the other necessary functions. But if the plant as a whole is to survive and if its kind is to survive, every part must be able to do its share well. Thus the plant is a partnership of parts. The activities of such a partnership of parts of a living thing, each part doing its own special work and contributing to the plant or animal as a whole, is known as *division of labor.*

Division of labor. Let us now make the same sort of general study of some other living thing which is totally different from the dandelion. A dog will serve. If the dog were anchored to one spot like the dandelion, he would soon die. He must roam in search of food, water, and shelter. Roots would be a fatal burden to a dog. To survive he must have some means of locomotion[1]; hence his legs. He has bones in his legs to hold his body up from the ground, so that it will not drag and hold him back in his necessary ramblings. He has two pairs of legs, each pair somewhat different from the other, because the pairs have different work to do. The dog has other bones to hold up his head, with its special organs,— ears, eyes, and nose,— so that he can locate food and detect the presence of enemies.

We could go on, as we did with the dandelion, pointing out a great number and variety of structures and parts of the dog, each of which performs some definite and necessary service for the animal. Each is a member of the partnership which is the whole dog. Each has its service to perform in the division of labor in order that the combination may be a dog.

In division of labor certain parts share their particular labors with similar parts. Thus we have two hands and two eyes. We could, of course, continue to live if we lost one hand or one eye. But in such a case the remaining hand or eye must do the work of both. A person has been known to live for years after his stomach had been removed. In such a case, however, the portion of the work of digestion which is ordinarily done by the stomach had to

[1] *Locomotion* (lo ko mo'shun): the act of moving or power to move from place to place.

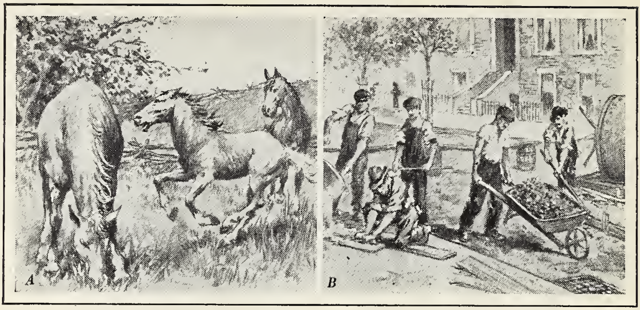

FIG. 11. Explain how division of labor in such an animal as the horse is similar to the division of labor of a gang of workmen. Explain in what ways it is different

be taken over, as best it could be, by other parts. It happens rarely, if ever, that an animal or a plant is able to carry on life as effectively after having lost some structure as if the original equipment were complete. Practically all parts are necessary in the division of labor (Fig. 11, *A* and *B*). Division of labor will be discussed many times in the chapters that follow.

Instructions for Taking the Tests. At the end of each problem you will find tests which will enable you to determine whether or not you know and can apply the important facts in the problem. You should be able to answer all these test items correctly. (Do not write in the book.) These tests will be of several types, but chiefly of the following three types:

1. *The Modified-True-False-Type.* In each of the items of this type one or more words are italicized. If the statement as given is not correct, make it so by changing one or more of the italicized words. Thus:

1. Biology is the study of *all living* things.
This statement is correct as given and needs no changes.
2. Biology is the *science* which deals with the study of *rocks*.
This statement is not correct as given, but can be made so by changing *rocks* to *living things*.

2. *The Completion Type.* Make each of the items of this type a complete and correct statement by supplying a word or phrase in the blank indicated by __(?)__. Thus:

The science which has to do with the study of all living things is __(?)__.
You would make this statement correct by adding the word *biology* in the blank.

3. *The Multiple-Response Type.* In each of the items of this type you are to select the one of the five or more endings which makes the statement correct. Thus:

The science which has to do with all life is (1) chemistry; (2) physics; (3) biology; (4) geology; (5) paleontology; (6) botany; (7) astronomy.

The only one of the seven endings given here which is correct is (3) biology.

In some cases with this type of item there will be several endings each of which is more or less correct. In such cases you are expected to select the best answer.

The explanations of how to answer the other types will be given with each type as it appears.

Self-test on Problem II-A. **1.** Energy cannot be either created or destroyed; it can only be *transformed*, or changed, from one *form* into another.

2. Matter cannot be either *created* or destroyed; it can only be transformed, or changed, from *one* form into another.

3. If no plants or animals should ever die, the time would finally come when *few* new plants or animals could be produced.

4. A flea which lives on a dog's back is a *saprophyte.*

5. A toadstool is a *saprophyte*, and hence is an example of *an independent* plant.

6. All green plants are *dependent* because they can make their own food.

7. A tree is an example of a *simple living* thing.

8. Teeth with which to chew food, and stomach and intestines with which to digest it, together are an example of __(?)__.

Problem II-B · What Kinds of Enemies must Living Things Fight, and How do they Protect Themselves against these Enemies?

* **Life a constant struggle against enemies.** As has been stated, the total amount of energy which is available to all the creatures on the earth is limited. There is not plenty for all. Consequently there is a constant struggle for survival.[1] Every animal or plant is forced to compete for energy with others of its kind and with living things of many other kinds. Every individual must some-

[1] *Survival* (sur vi'val): having to do with surviving, or continuing to live.

how succeed in securing energy enough to maintain life. Usually this can be done only at the expense of some other animal or plant.

In many ways men are like other animals. History is full of incidents in which stronger nations have made war upon weaker nations for the purpose of securing a larger amount of land or land that was more fertile upon which they could raise the food needed. Man is constantly at war with other animals, such as rats and insects, and with plants, such as molds and wheat rust, to prevent them, if possible, from reducing his precious stores of food to the point where he can no longer exist as comfortably as he wishes. Similarly all animals prey upon other animals or upon plants. Moreover the war to secure energy goes on just as severely among plants as among animals, though it is not so likely to be observed. The green plants can make their own food, but in order to do so they must grow fast enough or high enough or broad enough so as to keep a sufficient amount of their green surfaces exposed to sunshine. The stronger ones, therefore, crowd out or shade and thus kill the weaker ones, or they take for their own uses materials in the soil that are necessary to the existence of other plants. No mercy is ever shown in such warfare.

Kinds of enemies. Every living thing has its enemies. These enemies are not always other animals or plants. An enemy is anything which makes life difficult or impossible. An enemy is therefore anything (1) which takes some or all of a plant's or an animal's stores of energy; (2) which shuts off or diminishes its supply of energy; (3) which kills it at once or which injures it so that it can with difficulty continue its normal life; (4) which changes its habitat[1] in such a way that it cannot continue to live there.

One does not need to search far in order to find evidences of the constant struggle of living things against their enemies (Fig. 12). A study of any weed patch will no doubt furnish examples of the four types of enemies which have just been named.

Protection against enemies. As an aid to survival, animals and plants have various means of protection. Those which are most likely to be noticed are the hard coverings, or exoskeletons, of insects or of such animals as crayfish, crabs, and lobsters, or the

[1] *Habitat* (hab'i tat): the place and conditions in which an animal or plant lives.

FIG. 12. Which types of enemies are illustrated by this beaver (in Riding Mountain National Park, Canada) and this sand (near Lake Michigan)?

shells of snails or of "shellfish," such as starfish, sea urchins, clams, oysters, and barnacles. Animals like ourselves, which have skeletons of bones, are likewise protected to a great extent by these skeletons. The skull is a sort of box which surrounds and protects the delicate brain. The ribs form a kind of crate, inclosing the lungs, heart, and other organs. The hip bones form a sort of half-open box (pelvis)[1] which protects delicate organs. Many organisms, however, have means of protection which are not so obvious, but without which they would be unable to survive.

Protective[2] adaptations[3] of plants. The tender structures in the stems of plants are protected by the tough outer covering. In plants like corn and bamboo this outer covering is a tough rindlike structure. In plants like the trees and bushes the outer stem structures are bark. The bark of the sequoia trees of California sometimes attains a thickness of more than three feet and serves for protection not only against ordinary injuries and enemies but also against forest fires.

[1] TO THE TEACHER. For explanation of the purpose of terms in parentheses see Preface, p. v.

[2] *Protective* (pro tek′tiv): giving protection.

[3] *Adaptation* (ad ap ta′shun): a structure or a behavior which adapts, or fits, a plant or animal for living successfully in its environment.

FIG. 13. Which of the classes of protective adaptations are illustrated in these pictures, and which are not?

Some plants have developed thorns which serve to protect them from animal enemies. In such plants as the acacia and the nettle these thorns are modified[1] stem structures. In other plants, such as some roses and nearly all cactuses, the thorns are modified leaves. Some plants have juices which make them poisonous or unpalatable to animal enemies. Some are protected from certain animal enemies by the unpleasant odors given off by their leaves or flowers.

Protective adaptations of animals. The means which serve animals for protection include both those of fighting and of resisting or avoiding the attack of enemies (Fig. 13). It must be remembered, however, that the enemies of any animal may include not only other living things but also various weather conditions, such as changes in temperature and other factors. The protective means which aid animals in survival may be grouped in a few general classes. Some of these classes have to do with structures, while others are concerned with the products of plant and animal structures.

[1] *Modify* (mod'i fy): to change. *Modification* (mod i fi ka'shun): a change.

1. *Structures serving directly for offense or defense.* The stings of bees and the teeth of dogs are examples of such structures. Protective bony structures, such as the human skull; exoskeletons, such as those of insects; and shells, such as those of the oyster and the snail, belong also in this class.

2. *Adaptations of skin.* Any sort of skin serves to some extent as a protection against accidental injuries and against enemies, such as changes of temperature, bacteria, and biting or stinging animals (for example, certain insects). The skin of the rhinoceros is thick enough to serve as armor even against small bullets. Such special adaptations of skin as scales, fur, and feathers are especially important factors in the survival of many creatures.

3. *Artificial exoskeletons.* Some of the simplest animals build artificial shells around their bodies by cementing together tiny particles of sand. The larva of the caddis fly, which lives on the bottom of streams and is a food much liked by fish, protects its body with an artificial shell of tiny pebbles or twigs (Fig. 431, p. 661).

4. *Adaptations for speed.* Animals like the deer, the pheasant, and the trout are often able to escape from their enemies because they can run, fly, or swim faster than the latter.

5. *Adaptations for protective coloration.* Animals which are colored or shaped so as to look like part of their environment have better chances of escaping their enemies than those which are not so colored or shaped. Certain animals, such as the chameleon and the tree frog, change in color to correspond with that of the tree, rock, or other object upon which they happen to be resting.

6. *Products of specialized structures.* The skunk produces a fluid of such unpleasant odor as to cause other animals to avoid it. The octopus (Fig. 271, p. 414) when attacked is able to give off a black fluid which so clouds the water that the octopus can often escape unseen. The electric eel of the Amazon River is able to give a painful shock to an enemy near it in the water.

7. *Adaptations for producing a ferocious appearance.* The harmless hognose snake when in danger flattens its head and hisses in a very menacing way. The caterpillar of the Papilio butterfly sticks out two orange-colored "horns" when an enemy approaches.

Still other adaptations which serve as protection against enemies are observed in the behavior and the habits of certain animals: Thus some animals — for example, the common hognose snake and the opossum — will often pretend to be dead when they know an enemy is near. The hognose snake insists upon

lying on its back while playing dead. If turned over, it will immediately throw itself again upon its back with absurd haste. Other animals, especially certain of the birds which nest on the ground, will pretend to be injured in order to entice an enemy away from the nest. The mother bird will flutter, apparently almost helpless, just out of reach. She makes it appear that she is barely escaping from her enemy until she has lured it to what she considers a safe distance, whereupon she flies swiftly away. Many animals are able to escape blows by dodging. It is an amusing sight to see two bear cubs boxing with each other. Still other animals escape enemies by hiding in holes, in trees, or elsewhere. Others escape many enemies by hiding during the day and going about their activities only at night. A few escape detection by losing their characteristic odors. The newly born deer, for example, possesses no odor whatever. A dog with a keen scent will pass within a few feet of the motionless fawn and remain totally unaware of its presence. Other animals, such as the bees and the rats, find safety in numbers by living together.

Self-test on Problem II–B. 1. Select the best of the five endings to this statement:

A fierce struggle for existence is constantly going on (1) among plants; (2) among all living things; (3) among animals; (4) between the plants and man; (5) between certain animals and man.

2. Plants and animals have *no* enemies which are not living things.

3. *All* plants and animals have structures which serve for protection.

4. Select from the following phrases the one which does not belong with the rest: (1) artificial exoskeletons; (2) protective coloration; (3) ferocious appearance; (4) food and water; (5) extremely unpleasant odor; (6) spines and thorns.

Problem II–C · What is Man's Part in the Struggle for Energy?

***The balance of nature.** Although animals and plants are constantly engaging in a struggle for existence, whenever the animals and plants of a given region are left undisturbed, they finally establish a balance of nature. This expression means that the number of each kind of plant or animal remains approxi-

FIG. 14. Thistles are well fitted to compete for energy. How has the balance of nature been disturbed here?

mately the same. This number includes all that are able to compete successfully for food and other necessities with all the other animals and plants in that region. Left to themselves and without man's interference, animals and plants are not likely to kill off all the individuals of any kind. Such exterminations have occurred in a relatively few cases, and long periods of time were necessary to accomplish them. When a new plant or animal is introduced into a region, it may increase very rapidly at first, but after a time, if man does not interfere, its numbers remain relatively unchanged from year to year. Thus, when the English sparrow was first introduced into this country, it thrived so well and spread so quickly to all parts of the country that it seemed likely soon to exterminate many of our native song birds. But now its numbers are scarcely changing. Moreover, it has not exterminated any native birds. Therefore it is now finding its place in the balance of nature.

Unusually favorable conditions, as of food or weather, may cause a temporary increase in the numbers of certain plants or animals. Unusually unfavorable conditions may similarly cause a temporary marked decrease in their numbers. But when the unusual conditions end, the balance of nature is slowly established again (Fig. 14).

Man upsets the balance of nature. Man is responsible for disturbing the balance of nature more often than all other causes.

Primitive man of some twenty or thirty thousand years ago probably lived like the other animals. Hence he did not then disturb the balance of nature much more, if indeed any more, than they did. But when he developed sufficiently to become a farmer,— that is, when he first began to raise plants for his own use instead of searching the fields and forests for them,— he upset the balance of nature. He not only provided with an increased supply of food the insect and plant enemies of the plants he was cultivating, but he also concentrated his food energy in one place with the result that the insects could find abundance without traveling far for it. Similarly other animals were attracted by his crops and by his domesticated animals. When he learned to keep stored food during winter, this practice likewise invited attacks from animals that desired the food. The result was a great increase in the numbers of plants and animals which were competing with man for his energy supply. Furthermore, as man cleared the ground for his crops, he provided not only more space for weeds but also conditions favorable to their growth. As these weeds were vigorous of growth, they choked out his crop plants by shading them. They also appropriated to their own uses materials in the soil which the crop plants needed.

Man disturbs the balance of nature by searching the world for new plants and animals for his uses. When he takes a plant from its original habitat, he aims to bring the plant but not its enemies. Hence without these enemies the transplanted plant or animal sometimes multiplies so rapidly in the new environment as to become a pest. The water hyacinth, a beautiful plant, got a start in this way in the inland waters of some of the Southern states, where, without its usual enemies, it multiplied so rapidly as to hinder navigation in certain rivers.

Man disturbs the balance of nature by introducing pests with his commerce. The European corn-borer, the Japanese beetle, the Mediterranean fruit fly, and many other pests were thus brought into this country undetected, with commercial products. None of these insects is a serious pest in the regions from which it came because there it has a sufficient number of enemies to keep its numbers in control. But here without these enemies it multiplied so rapidly as to become a serious menace to certain food crops.

Man disturbs the balance of nature by spreading plant and animal pests with his travel. Insects and seeds often are carried on radiator shields and other parts of an automobile and in camping equipment from one part of the country to the other.

Lynwood M. Chace

Fig. 15. These young Cooper's hawks belong to an undesirable species. Explain

Man disturbs the balance of nature by killing species harmful to himself (Fig. 15). Years ago the farmers in certain states found that hawks were preying upon their chickens. They therefore passed a bounty law, offering money for every hawk killed, hoping thus to exterminate the birds. Hawks were killed in great numbers. The farmers did not know then that in killing the hawks they were disturbing the balance of nature by removing an important enemy of the field mice and other small animals which attack grain crops. Soon, with the numbers of hawks diminished, those animals multiplied so rapidly as practically to destroy the wheat crops. The farmers then repealed the bounty law on hawks and passed another law providing a fine for anybody who killed one. The surviving hawks found unusually large numbers of small animals, and with this abundant food supply the birds multiplied rapidly. In a few years the balance of nature was again restored.

Man disturbs the balance of nature by hunting, trapping, and fishing for food, profit, and pleasure. In pioneer days game animals and food fishes were abundant. But the white man when unrestrained by law soon changed this condition. Sturgeon were caught in the Columbia River by the ton and, after their roe was removed, were left to rot on the river banks. Song birds were killed in enormous numbers for their feathers to put on women's hats. Elk were killed for their teeth. These are only a few of many examples which might be given of the wanton destruction of wild life.

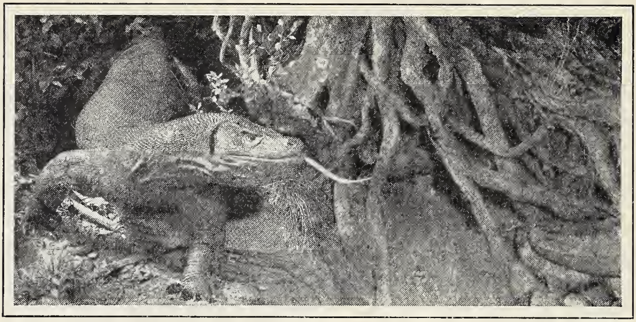

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FIG. 16. These huge "Dragons of Komodo" are protected by the Dutch government, which owns Komodo, an island east of Sumatra and Java, upon which they live. These animals are of no use whatever to man and are exceedingly ferocious. Why should they be protected?

Man attempts to restore the balance of nature by conservation. Realizing that the rapidly vanishing wild life must be protected, national and state governments have passed laws for its protection (Fig. 16). Several societies have been organized for the same purpose, and many private citizens have given their time and money generously in the same cause. The various means adopted for the conservation of wild life are discussed in Chapter XXVI.

Self-test on Problem II–C. 1. If the animal population in one of the national parks remains unchanged for many years, it is *probable* that the balance of nature has been established there.

2. List the various ways in which man upsets the balance of nature.

3. Man has introduced many types of *conversation* as a means of preserving wild life.

Self-test on Biological Principles. How would you explain these principles to someone who had not studied biology?

1. The plants and animals in a given environment depend upon one another.

2. The plants and animals in a given environment are engaged in a constant struggle for energy.

3. Protective adaptations are an aid to survival.

4. Division of labor is found in familiar plants and animals.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Give an original example illustrating (1) energy cycle; (2) matter cycle; (3) division of labor.

2. Why is not an artificial shelter, such as a muskrat or beaver lodge or a man's house, listed as one of the classes of protective adaptation?

3. A toad has poison glands in the skin of its back. Should a dog eat the toad, the dog would die. Do you consider this adaptation a means of protection for that toad? Explain.

4. Can you see any ways in which man's use of domestic animals disturbs the balance of nature?

5. Did Robinson Crusoe disturb the balance of nature on his island? Explain.

6. Describe several adaptations which you have observed in plants; in animals. How are these of advantage to the plant or the animal in the struggle for energy?

7. Under which of the four classes of enemies would you place each of the following: a manufacturing company which by emptying waste products into a river makes the water unsuitable for fish; a sparrow which snatches a worm from a robin's beak; a big tree which shades a smaller one; a stream which washes out a tree; a hailstorm which breaks down small plants and knocks branches from trees; a dandelion growing in a lawn?

8. Under which of the seven classes of protective adaptations does each of the following belong: the chrysalis or cocoon of an insect; a growling dog with bared teeth; a white ptarmigan (grouse) in the snow; the armor of a crocodile; a knight in armor; the spurs of a rooster; a bird flying when another animal approaches; the odor that a shrew gives off and that drives away many larger animals which otherwise would eat the shrew?

Project 1. To collect examples of protective adaptations. Keep a record of every sort of protective adaptation, such as those described on pages 27–28, which you observe that animals and plants possess or use. Try to list the examples you find under the various kinds, or types, of adaptation described.

Chapter III · Life Necessities

Questions this Chapter Answers

In what sense is each of the following conditions a factor which makes possible or which limits life: food, heat, light, oxygen, weather, climate, water, physiographic features, shelter, soil, relations with other living things, and changes in the environment?

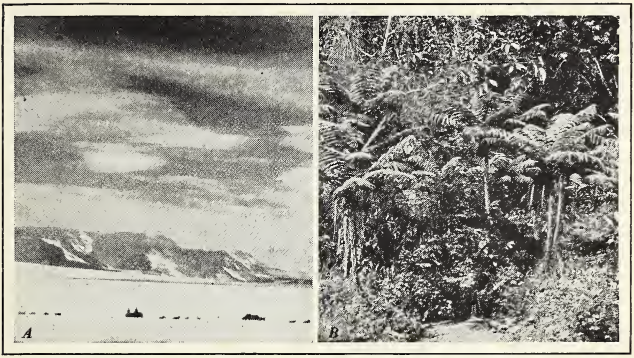
Problem III–A · How is Life Related to Certain Forms of Energy and to Certain Factors and Conditions of the Air?

Factors and conditions necessary to life or limiting life. When the great explorers Byrd, Peary, Amundsen, and Scott made their famous expeditions into the forbidding polar regions, they carried with them all the food which the men and dogs would require during the long months of their stay. They knew that they would not find native animals and plants which would serve for food. Where Byrd made his main camp, on the ice shore of the Antarctic Ocean, there were a few animals, such as seals and penguins, and in the arctic regions in general there are polar bears, walruses, and seals. But on the great wastes of ice and snow at the north and south poles there are no visible living things whatever (Fig. 17, *A*).

Contrast the barren snow and ice deserts of the north pole and the south pole with the jungles of the equator (Fig. 17, *B*). Here life is more abundant than in any other part of the world. If all the creatures living in one square mile of jungle could be found and classified,[1] the number of different kinds would doubtless run into thousands.

Why is it that life is so abundant in some parts of the earth, while it scarcely exists at all in others? The reason is that life can exist only under certain conditions of the environment and

[1] *Classify* (klas′i fy): to put things into groups, or classes, in accordance with some respect in which they are similar. *Classification* (klas i fi ka′shun): act of classifying or the result of classifying.



Dr. Laurence M. Gould

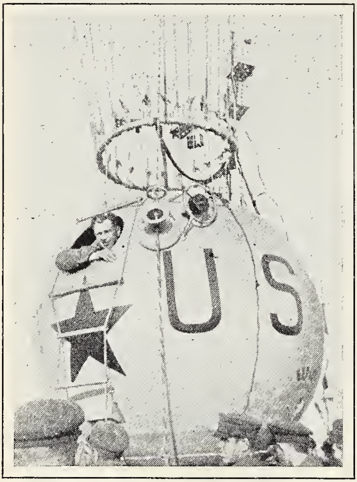
Fig. 17. What are some of the biological problems which the men and the dogs in picture *A* and the plants in picture *B* had to solve in order to survive? (*A*. Dr. Gould's geological party, which accompanied Commander Byrd on his first south polar expedition)

when certain factors are present in the proper degree. Certain of these environmental[1] factors are necessary to all life; others are necessary to most life; some are necessary in indirect ways. Not only are these factors, or conditions, essential to life, but also by their lack or abundance they regulate the numbers and kinds of plants and animals which may exist in various regions.

***Food energy.** As has previously been stated, every living thing must secure energy in the form of food. Abundance of food is therefore one of the chief factors affecting the numbers and kinds of animals and plants. It is not uncommon to find land upon which trees, crops, flowers, and even grass will not grow. Such land is called "poor soil." This term usually means that the soil does not contain certain substances which the plants need as raw materials for their food-making. An abundance of food often causes an enormous increase in the number of animals and plants. A shortage of food causes a corresponding decrease because the weaker ones, especially, die in great numbers. In thickly populated districts, such as certain parts of China, after

[1] *Environmental* (en vi ron men't'l): having to do with the environment, or surroundings.

long-continued periods of drought, famines have resulted in which thousands of people have died. Some have starved to death, and others, because of weakness due to insufficient food, have become an easy prey to various diseases.



Wide World

Fig. 18. The gondola in which three Russian scientists ascended 11.8 miles above the earth, September 10, 1933. What biological problems did these men need to solve, to remain alive and comfortable at that height?

Many animals can live for relatively long periods without food. There are on record cases in which people have fasted for several weeks without apparently suffering ill effects. Horned toads and alligators can live for several months without eating, and certain insects have been observed to live for several years without food.

Heat energy. Certain of the lower plants (algæ) can carry on their life activities at temperatures above that of boiling water. Certain of the bacteria which cause food to spoil have been known to remain for hours without apparent injury in a temperature of about − 216° C. (216 degrees below zero centigrade). But no animal or plant can carry on its life processes at extremely high or extremely low temperatures. The higher animals and plants have a much narrower range of temperature in which they are able to survive than have some of the lower forms of life. Man, however, by applying science is able to endure the low winter temperatures of the polar regions and of the atmosphere several miles above the earth (Fig. 18).

Light energy. Light is necessary to the existence of most living things, because it is essential to green plants in their manufacture of food. Many plants and animals, however, can live in the dark (Fig. 19). Fish with undeveloped eyes but otherwise

Dr. Frank E. Nicholson

Fig. 19. This salamander was found in a newly discovered cave at Long Horn State Park, Texas. Where there is no light, living things are not likely to develop color. Can you think of a reason to explain this fact?

similar to the same kinds of fish found elsewhere in rivers and lakes have been found in the river flowing through the Mammoth Cave of Kentucky. Some of the animals in the depths of the ocean live without any sunlight whatever, as do also parasites which live entirely within the bodies of their hosts. Many animals — for example, the centipede and the sow bug — avoid light. Some of the bacteria cannot exist except in profound darkness. All bacteria are killed by long exposure to direct sunlight.

The amount of sunlight during the year at various parts of the earth determines to a large extent the numbers and kinds of plant and animal life.

***Oxygen.** Oxygen, which makes up about 21 per cent of the volume of the air, is used in the life processes of all living things. There are many animals and plants which cannot take their oxygen directly from the air, as do men and the higher animals. We are familiar with the fact that fish "drown" if they are exposed to air for more than a short time. Oxygen is around them in abundance, but they are unable to use it unless it is dissolved in water. Some bacteria (anaërobic), moreover, cannot use oxygen either in the form of a gas or when dissolved in water, but only when it is combined with certain other substances.

Carbon dioxide. Carbon dioxide, which makes up about .03 per cent of the air, is necessary to all green plants in their work of food-making. It is therefore necessary indirectly to all living things. How carbon dioxide is used by green plants will be discussed in Chapter V.

Weather. Weather conditions are responsible for temporary changes in the animal and plant population. If the winter is unusually cold, there is likely to be a much smaller insect population during the following summer than if the winter is mild. Fruit and nut trees have been practically exterminated[1] in certain sections as the result of a winter of severe and long-continued cold. Similarly, unusual periods of drought or wet weather affect greatly the number of plants and animals. Such conditions not only reduce or increase the food supply but also may produce conditions that make difficult (Fig. 20) or impossible the existence of various sorts of animals and plants.

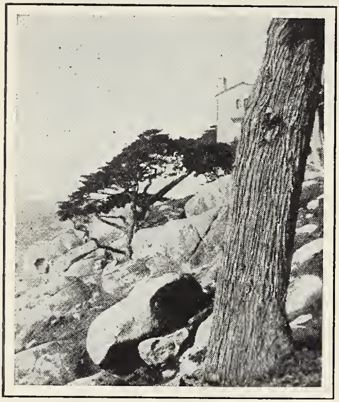


Fig. 20. From what direction do the prevailing winds blow as indicated by the trees?

Climate. Contrary to the belief of many people climates do not change except over long periods of hundreds or thousands of years. Nevertheless they do gradually change; and as they change, the plants and animals which can live in them must likewise change, or they must migrate. Fossils[2] of animals closely related to elephants have been found in various parts of this country and even in the arctic regions. During the glacial age, when vast sheets of ice covered much of the northern hemisphere, no life was possible in Alaska, Canada, and the northern part of the United States, which then lay under the ice. At other times much of central United States was covered by dense tropical forests. Whether the climate is tropical, temperate, or arctic determines

[1] *Exterminate* (ex ter'mi nate): to destroy utterly, as all the animals and plants of a certain kind. *Extermination* (ex ter mi na'shun): act of exterminating.

[2] *Fossil* (fos'il): the forms or remains of ancient plants or animals preserved in earth or rock.

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Fig. 21. Plant life on Mount Rainier, Washington. What conditions prevent the plants from growing to the top of the mountain?

largely the nature and abundance of life. Thus certain trees and other plants and animals are found only in certain regions determined by climate. Such regions do not have definite boundaries (Fig. 21).

Self-test on Problem III–A. **1.** A cow or a horse could not live at the north pole or the south pole because (1) there is no sunshine at the poles; (2) nothing can live at the poles; (3) such animals cannot live without man's protection; (4) there are no green plants at the poles; (5) certain factors and conditions necessary to the life of the higher animals are not found at the poles; (6) there is no fresh water at the poles.

2. *Few* plants and *no* animals can exist without securing food energy.

3. A *rapid* increase in the number of animals or plants in any place may be due to a sudden *decrease* in the amount of food available.

4. If there were *no* sunlight on the earth, there could be *no* life.

5. Oxygen is necessary to *most* plants and to *some* animals.

6. Weather and climate affect the abundance of living things (1) not at all; (2) little; (3) somewhat; (4) to a slight extent; (5) considerably; (6) to a great extent.

7. Carbon dioxide is essential to *all animals.*

Fig. 22. Self-test on Biological Principles: How do these pictures illustrate the biological principle "Water affects the abundance of life"?

Problem III–B · How is Life Related to Certain Other Factors of the Environment?

***Water.** Since water is always given off as a waste product by every living thing, fresh supplies are necessary. Most animals and plants must secure water at relatively short intervals, though some of the lower animals and plants are able to exist for months and even years without renewing the water supply in their bodies.

Rainfall is a factor which operates powerfully in controlling life. The plants and animals which live in desert regions are usually very unlike those which live in regions where there is abundant water (Fig. 22). They must be different in order to survive. For example, if a cactus and a horned toad from the desert in southwestern United States were to exchange habitats with a swamp plant and a frog, neither pair would be able to live long in the habitat of the other.

When for any reason the supply of water becomes too scanty for the needs of living things in any region, the animals and plants must (1) somehow adjust themselves to living for longer intervals without water, (2) increase their water supply artificially, or (3) migrate to a more favorable habitat. Only man and a few of the other higher animals, such as the beaver, can increase the water

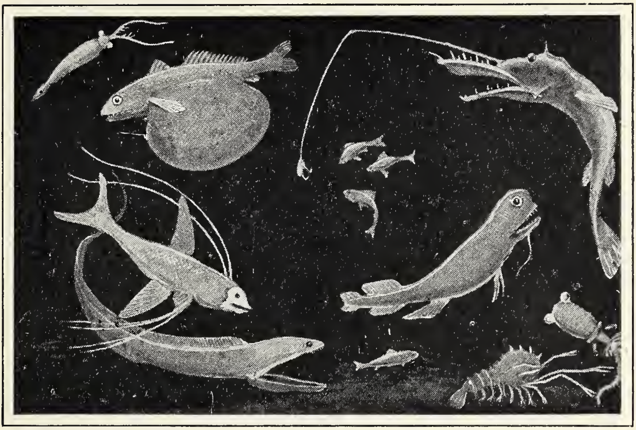


FIG. 23. These fish live four or five miles below the ocean surface, where there is enormous pressure and no light except that which they themselves produce. What sort of food should you guess that they eat? Justify your answer

supply artificially by storing it or by bringing it from distant lakes or rivers. Animals and plants are sometimes able to make necessary adjustments to a changing water supply over periods of thousands of years, provided the changes in water supply occur very slowly. But in such cases the adjustments consist of more or less pronounced changes in the animal or plant itself. Thus desert plants and animals have become adapted to a habitat in which in some cases months or even years may elapse between rains. Such living things have become able to store greater quantities of water in their bodies, to get along with an exceedingly small amount of water, and in either case to give it off very slowly.

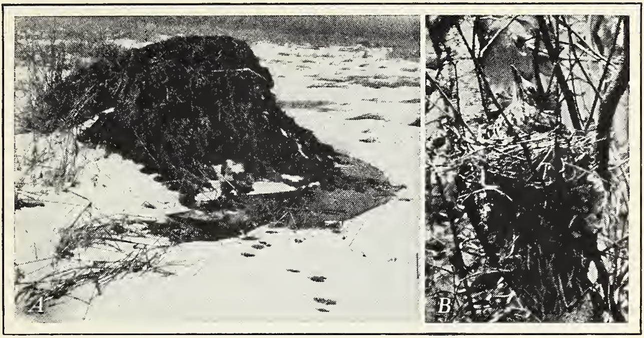
Water as a habitat is an important factor in limiting life. It limits the numbers and kinds of animals in three ways, depending upon (1) whether the habitat is entirely water or is dry land; (2) whether it is shallow water or deep water; (3) whether it is fresh water or ocean water. We are all familiar with the fact that animals and plants which live entirely in the water are very different from those which live entirely upon the land. Fish and

FIG. 24. *A*, rock barnacle; *B*, goose barnacle. The barnacle is a close relative of the insects and crabs. How many factors necessary to the life of this animal can you name?

water plants soon die if removed from water, while land animals and plants suffer the same fate if they are kept immersed[1] in water. Moreover, the animals and plants which inhabit the shallow water of fresh ponds and the margin of the ocean are very different from those which live in the deep water of the Great Lakes and the ocean — in fact, in the profound depths of the ocean there are relatively few living things (Fig. 23). Some animals and plants — for example, the salmon and certain of the bacteria — can live both in fresh water and in the ocean. Others, like goldfish and pond plants, cannot live if they are taken from fresh water into the ocean. Still others die if they are taken from the ocean into fresh water. An example of this latter type of animal is the barnacle (Fig. 24), which lives fastened to rocks or to floating objects, such as the bottoms of ships. If, however, the ship enters a fresh-water harbor, the barnacles all die and drop off or are easily removed. Another example is furnished by sponges, which sometimes fasten upon the shells of oysters in such numbers as to starve the oysters by robbing them of their food supply. In order to prevent this, "oyster farmers" sometimes grow their oysters upon frames. When it rains, they raise these frames above the salt water. The rain soon kills the sponges; but the oysters, protected by their shells, are unhurt by it.

Physiographic features. The physiographic features, such as mountain ranges, deserts, rivers, plains, forests, and the ocean, sometimes serve as barriers which hold certain kinds of animals and plants more or less within certain boundaries. Thus Australia

[1] *Immerse* (i merce′): to submerge, or force beneath the surface, as of water.



Lynwood M. Chace

FIG. 25. *A*, muskrat house; *B*, wood thrush on nest. What are the differences in the functions of these two types of animal shelters? Note the fox tracks in front of the muskrat house

has a number of plants and animals, such as the kangaroo (Fig. 383, p. 590) and the platypus (Fig. 158, p. 240), which, because of the oceans surrounding Australia, have not spread to other lands.

Shelter. Shelter is essential to some living things during part of their lives and to others during all their lives. Some animals and plants can find such shelter as they need, but others must make their own. Bears and other animals spend the winters in underground caves or in hollow stumps; insects and snakes seek holes in the ground or deep rock crevices; many plants and animals find shelter from the cold beneath the winter snows.

All parasites which live inside the bodies of other organisms must have the shelter of the bodies of their victims, or hosts, in order to survive. The fur or feathers of other animals furnish shelter to such parasites as fleas and lice, which live upon the skins of animals and birds.

Many living things make shelters. Insects of many kinds make cases, or cocoons, in which to live safely while developing into the adult, or full-grown, state. Others bore holes in trees or dig holes in the ground to serve as shelters for their eggs and larvæ. Birds and some kinds of fish build nests in which to shelter their young (Fig. 25, *B*). The young of all the higher animals are

sheltered before birth in the bodies of their mothers. Many animals, such as beavers, squirrels, and mice, build shelters in which to spend the winters (Fig. 25, *A*).

Soil. Soil is a limiting factor of the environment. The nature of the soil and its thickness determine to a great extent the numbers and kinds of animals and plants which can inhabit a given region. The higher forms of plant life, such as trees, do not thrive best where the soil is shallow or scanty. Any boy who has hunted for earthworms knows that he is not likely to find them in heavy clay or in sand, but that they will be abundant in soil that is rich in decaying animal and vegetable matter. Other soil conditions which limit plant and animal life will be discussed in later chapters.

Relations among living things. Plants and animals, especially man, are themselves limiting factors of life. The preceding chapter described how plants struggle with one another for possession of ground and sunshine. It also discussed dependent animals and plants, which prey upon other animals and plants. Among these dependent plants parasites were mentioned. Most diseases of animals and plants are caused by parasites of one sort or another.

Here and there in nature are found certain curious partnerships of living things. Life in the environment in which they live would be difficult or impossible for either alone. Together they survive because each contributes something necessary to the other's welfare. Thus in the shallow water on the ocean beach one often finds a tiny hermit crab with its tender body thrust into a discarded shell for protection. Sometimes one finds one or more small hydroids growing on the same shell near the open end (Fig. 26). The hydroid benefits the crab as well as itself because with its stinging organs[1] it keeps enemies away from the shell. The hydroid benefits from its association with the crab, since, by being carried about as the crab drags the shell along, it secures a more plentiful and varied food supply than it would secure if anchored to a rock. Such a helpful association is an example of symbiosis.[2] Another example of symbiosis is furnished by the

[1] *Organ* (or'gan): a portion of an animal or plant which accomplishes certain work.

[2] *Symbiosis* (sim bi o'sis): such an association of two totally different things as results in benefit to each.

lichens, which grow in patches on rocks, bark, and the like (Fig. 27). The lichen is really two plants in partnership. One, an alga, which has chlorophyll, is held by the other, a fungus, which has no chlorophyll. The alga manufactures food which is used both by itself and by the fungus, while the body of the fungus secures and stores water which is used by both. Moreover, the alga finds support and shelter from the body of the fungus. A third example is supplied by the rhinoceros and a certain species of bird, which live in close association. The bird profits from the association by eating insect parasites from the rhinoceros's back. The rhinoceros profits by getting rid of its parasites and also by being warned by the behavior of the bird when danger approaches.

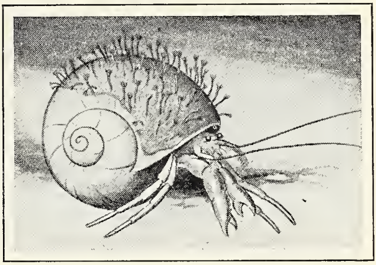


Fig. 26. A partnership between a hydroid and a hermit crab. How does this picture illustrate symbiosis?

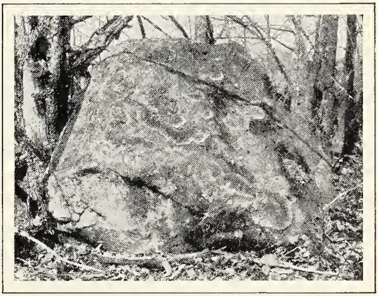


Fig. 27. A plant partnership. How do the two plants which make up the lichen aid each other to survive?

Changes in the environment. Many changes due to natural causes often prove limiting factors of life. A forest fire renders the burned section unfit for many kinds of plant and animal life for many years. Sands shifting slowly but steadily year by year may not only kill vegetation in their path but render the region unfit for new vegetation. Ashes and fumes from an active volcano may so blanket the country surrounding the volcano as to make life of any sort impossible.

***Summary.** The preceding discussion has shown that certain environmental factors are necessary to all life. These are water, oxygen, food, heat, and certain conditions of climate and weather. Other factors which are necessary directly or indirectly are light, carbon dioxide, and shelter. All these factors by their abundance or scarcity limit the numbers and kinds of animals and plants. So also do certain other factors, such as the topography, or physical features, of a region, other animals and plants living in it, the depth and character of the soil, and change in the environment due to natural causes. When any animal or plant finds environmental conditions unfavorable to its existence, it must (1) migrate, (2) adapt itself to the changing conditions, or (3) be exterminated.

Self-test on Problem III–B. 1. Select from the following list of factors those which are directly necessary to all life: (1) light; (2) other living things; (3) water; (4) favorable weather; (5) soil; (6) extermination of some other plant or animal; (7) food; (8) shelter; (9) heat; (10) slow changes in the environment; (11) oxygen; (12) migration to other regions; (13) the ocean; (14) plains, rivers, and mountains; (15) man; (16) rainfall; (17) carbon dioxide.

2. Is there any factor in 1 which no living thing would ever need?

3. Suppose some wild animal, such as a deer or a bear, should be living in a locality in which no rain fell for several years. What would the animal need to do in order to survive?

Self-test on Biological Principles. What evidence can you cite from this chapter to illustrate this biological principle: "The environment acts on living things, and living things act on their environment"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Why were the polar explorers unable to use the abundant sun energy in the polar regions?

2. What observations have you made which indicate other ways than those given in this chapter in which living things are affected by light?

3. Below the falls of the Zambezi River, in Africa, is a small island upon which the mist from the falls descends like rain without ever ceasing. Can you name animals and plants which you feel certain could not survive in such a habitat? What should you expect would be some of the characteristics of the plants which do live there?

4. What examples of artificial shelters other than those mentioned in the text can you name? Can you name any animals or plants which can live their entire lives without shelter of any sort? What relation has shelter to our definition of biology on page 4?

5. Can you name other examples than those discussed in this chapter of plants and animals which can exist only under certain soil conditions?

6. How does man's progress toward making homes and cities more sanitary serve as a factor limiting certain kinds of life? Can you name other activities or achievements of man which serve as factors limiting life?

7. Can you name other examples of changing environment, similar to those mentioned on the preceding page, which might limit life?

8. What animals and plants can you name that have become extinct in your locality during the last century or so? Can you name any animals or plants which have entirely disappeared from the world during the past few hundred years? Can you find out the causes of their disappearance?

Chapter IV · Living and Nonliving Things

Questions this Chapter Answers

What is protoplasm, and what are its characteristics?
What are the functions of protoplasm?
What is the cell theory?
What are the characteristics of a cell?
What are tissues and organs?
How are living things like and how are they unlike nonliving things?
What are some of the characteristics of elements, compounds, and mixtures?
What are the characteristics of organic and inorganic matter?
What is the relation of oxidation to energy?
What are physical and chemical changes?
What is osmosis?

Problem IV–A · What are Some Important Characteristics of Living Matter?

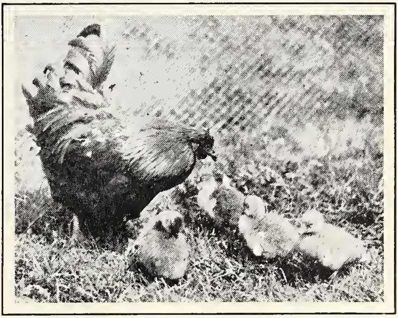
***Only protoplasm is alive.** An elephant does not apparently resemble an oak tree, nor does a cat seem much like a cabbage. Yet these plants and animals are much alike because all the living parts of all plants and animals are composed of essentially the same material, called protoplasm. The protoplasm found in one living thing looks very much like the protoplasm found in every other living thing, though protoplasm is never exactly the same in two different kinds of plants and animals. Moreover, protoplasm differs somewhat not only in different living things but in different parts of the same living thing. And it is constantly changing, wherever it is.

Protoplasm is neither solid nor liquid. It is somewhat like white of egg and somewhat like jelly; yet it is to some extent elastic. It is usually colorless or slightly yellow — sometimes gray. It is usually transparent but sometimes opaque. Sometimes it appears frothy or granular.[1]

***The functions of protoplasm.** Only the living parts of animals and plants are protoplasm. Heartwood, finger nails, and the bony

[1] *Granular* (gran'u lar): made up of granules, or little grains of substance.

part of teeth are not protoplasm, though they are produced by protoplasm. All protoplasm, wherever it exists, carries on certain functions, such as nutrition, respiration, reproduction and growth, irritability, and excretion. *Nutrition* is the process of securing energy in the form of food materials. *Respiration* includes breathing and the processes within the protoplasm which accompany the use of oxygen. *Reproduction* and *growth* are processes by which new protoplasm is made. Hence reproduction may result in new cells or in new individuals. *Irritability* is the ability to respond to stimuli,[1] such as heat, chemicals, jarring, light, sights, and sounds. *Excretion* has to do with getting rid of waste products. The term *metabolism*[2] is used to include all processes concerned with the use of food by protoplasm.



Newton H. Hartman

FIG. 28. What important functions of protoplasm are here illustrated?

Since all the living parts of every animal or plant are composed of protoplasm, every creature must pass through certain stages in life. It starts life as an individual, it grows to maturity, it grows old, and finally it dies. Since every animal and plant is almost wholly protoplasm, it follows that every living thing must carry on the functions of protoplasm which have been mentioned. Every kind of animal and plant reproduces. Thus, though every living thing dies in a longer or shorter time, life is passed on (Fig. 28).

[1] *Stimulus* (stim'u lus): any influence outside a living animal or plant which causes a response from the animal or plant. *Stimuli*, plural of *stimulus*.

[2] *Metabolism* is divided by biologists into anabolism and catabolism. *Anabolism* includes all the processes concerned with building protoplasm from simpler substances. *Catabolism* includes all the processes concerned with breaking down protoplasm into simpler substances. Anabolism and catabolism are going on constantly in all parts of every living thing.

The cell. ***Experiment 1.*** What are some of the characteristics of a living cell? With a knife remove some of the thin skin from one of the layers of an onion. Mount a single thickness of this on a microscope slide. Adjust the slide under the low-power objective of a compound microscope. What do you see? You are observing living cells. Add to the material on the slide a drop of weak tincture of iodine or of iodine crystals dissolved in water. Do you now observe any structures in addition to those which you saw before you stained the slide? Make a careful study of the materials under the high-power objective. Make sketches and record your observations so that you will have a complete report of your study of onion cells.

With a knife blade or a toothpick scrape some of the material from the inside of your cheek. Transfer a little of this material to a microscope slide. Study the epithelial [1] cells in it in the same manner in which you studied the cells in the onion skin. Study also the cells of *Pleurococcus* or those in the young leaves of *Elodea* or in the hairs on the young stems of a squash, a geranium, or a spider lily (*Tradescantia*). Do you find any structures in any of these cells which were not present in the onion?

From your observations of these various kinds of living cells, what have you learned concerning the characteristics and structure of the cell?

Exercise on scientific method [2] ***(evaluating procedures).*** Why was it desirable to examine a number of different kinds of cells?

The cell theory. The earliest knowledge of cells was obtained from a study of plant structures. In 1665 Robert Hooke while studying a section of cork under a lens saw that the cork had a regular arrangement of little spaces. These he called cells because they reminded him of the cells, or rooms, occupied by monks in a monastery (Fig. 29). Since cork is dead material, he saw only the cell walls. Protoplasm was not discovered until more than a hundred years later. Meanwhile the cell walls were considered the most

[1] *Epithelial* (ep i the'li al): having to do with the epithelium, or the layers of cells covering the surfaces of the body and its organs.

[2] Throughout this book there are many exercises on methods which scientists use in their investigations. These methods include those used in locating problems; making hypotheses, or generalizations, from given facts; recognizing errors and defects in conditions or experiments described; evaluating data or procedures; evaluating conclusions in the light of the facts or observations upon which they are based; planning and making new observations to find out whether certain conclusions are sound; making inferences from facts and observations; inventing check experiments; using controls; isolating the experimental factor.

Fig. 29. Robert Hooke studied with his microscope an endless number of objects, among them fish scales, flies' feet, and nettle stings. Which of the scientific attitudes (pp. 12–13) does his work represent?

important part of the cell. In 1838 Schleiden first announced the theory that all plants are made up of cells. In the following year, combining Schleiden's results with his own, which he secured from investigations of animal structures, Schwann announced what is now known as the *cell theory*. This theory states that *the cell is the unit of all life, and all plants and animals are made up of cells.* Some of the work of Schleiden and Schwann was inaccurate, and thus some of their conclusions from their observations are now known to be false. Nevertheless the modern cell theory, which has been built up on the work and publications of these two men, is regarded as one of the "foundation stones of biology."

The nature of the cell. The simplest plants and animals consist of only one cell. All others consist of more than one cell. Typical animal cells are small, usually about one two-hundredth of an inch long, wide, and thick. They vary greatly, however, in size. Some single-celled parasites are so small that they cannot be seen even through the strongest microscope. Certain one-celled animals are nearly an inch long by an eighth of an inch broad and thick. Certain nerve cells are several feet long; but these are threadlike and are not more than one thousandth of an inch thick, except at the central body, or nucleus, which is somewhat larger. Plant cells are in general larger than animal cells. The size of a plant or an animal depends not upon the size of its cells, but upon the num-

ber of cells which compose its body. The larger the animal or plant, the more cells it contains. It is estimated, for example, that the gray matter in the human brain contains nearly ten billion cells.

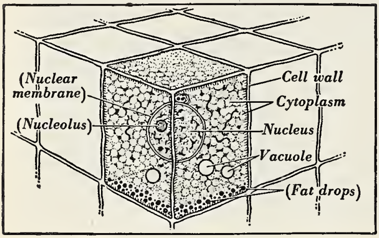


FIG. 30. The cell is the unit of living matter. Explain[1]

*Every cell is composed of protoplasm (Fig. 30). This protoplasm consists of two parts, the cytoplasm and the nucleus. The cytoplasm, which is thin and watery, occupies almost the entire cell. If you were observing closely in Experiment 1, you may have seen the cytoplasm moving within the cells of *Elodea*, geranium tips or hairs, or squash hairs. The nucleus, a round body somewhat less watery than the cytoplasm, is embedded[2] in the cytoplasm. A few cells have been observed which have no definite nucleus, but most of these have nuclear[3] materials scattered about in the cytoplasm. The cytoplasm and the nucleus, therefore, are essential to every living cell. Some animal cells contain globules of fat (Fig. 31). Plant cells often contain vacuoles, which are spaces filled with air or sap. Each cell has around it a membrane or thin layer of denser cytoplasm which holds the cell together and prevents the escape of protoplasm. Some cells have in addition a cell wall. In plant cells this wall is composed of a firm material called cellulose. No animal cells have cellulose walls, and therefore in general animal cells can be more easily changed in form by pressure than can plant cells. The cells in an animal or plant are not entirely separate units. During their active period adjoining cells are connected through their walls with tiny threads of cytoplasm. Other structures of the cell and the functions of the various cell structures will be described and discussed later.

[1] Labels in parenthesis are not intended as essential vocabulary (see Preface, p. v).

[2] *Embed* (em bed′): to lay partly or wholly within a body.

[3] *Nuclear* (nu′kle ar): having to do with the nucleus.

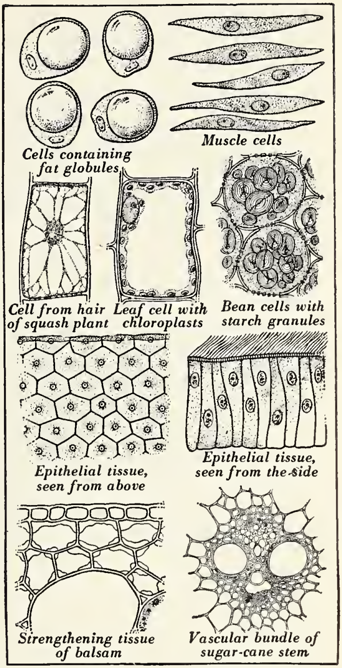


FIG. 31. In how many respects are these typical plant and animal cells and tissues alike and in how many respects are they different? How many reasons can you give to account for the fact that the different tissues are not exactly alike?

* **Tissues.** In Experiment 1 an examination of the onion skin and of material from the inside of the cheek showed many cells in each specimen. These cells were much alike in any one kind of material, but very unlike in different kinds of material. A group of similar plant or animal cells which exist together and are adapted for a similar purpose is called a *tissue.* Thus in the human body there are epithelial tissue, muscle tissue, nerve tissue, connective[1] tissue, and glandular[2] tissue.

* **Organs.** Groups of tissues together form organs. The simplest organs may be made up of only one kind of tissue; but usually an *organ* is composed of several kinds of tissues, each performing certain functions. Thus in such an organ as a plant leaf the tissue on the outer surface is so formed as to protect the tender inner parts and to make possible the entrance of air and the elimination[3] of waste products. Tissues inside the leaf are concerned with the manufacture of food. Running through the leaf are veins of tissue which give

[1] *Connective* (kon ek'tiv): used to connect, or join.

[2] *Glandular* (glan'du lar): pertaining to or having to do with a gland (see Glossary).

[3] *Eliminate* (e lim'i nate): to get rid of. *Elimination* (e lim i na'shun): the act or process of eliminating.

support and shape to the leaf. In an organ like the human heart there are several kinds of tissues, among which are muscle tissue, connective tissue, nerve tissue, and epithelial tissue. The tissues which are found in one kind of animal or plant are never exactly like any tissues found in any other kind of animal or plant.

It is easy to understand how division of labor can take place in an organ when one understands that an organ is composed of different kinds of tissues, each made up of certain cells capable of doing certain kinds of work.

Self-test on Problem IV–A. **1.** Which of the following words or phrases describe protoplasm: (1) dead animal material; (2) solid; (3) somewhat like jelly; (4) reddish brown; (5) slightly yellow or without color; (6) occasionally transparent; (7) occasionally opaque; (8) sometimes appears to be made of grains; (9) usually permits objects to be clearly seen through it; (10) always living; (11) every bit like every other bit?

2. Name other qualities of protoplasm which are not listed in 1.

3. One but not more than one item in A describes or illustrates each of the items in B. Match each item under B with one under A. The items under A may be used more than once in matching different items under B.

A	B
Nutrition	Answering when somebody speaks to you
Young pig	A mother cat and her kittens
Excretion	Loud thunder
Unit of living structure	Eating an apple
Respiration	Taking a deep breath
Irritability	Getting rid of excess salt along with perspiration
Toenail	
Reproduction	
Stimulus	
Beefsteak	
Oxygen	

4. *Most* living cells can be seen with the eye.

5. Division of labor can take place in a *cell.*

6. A *tissue* is composed of many similar cells.

7. All living things are composed of *cells.*

8. The eye is an example of *a tissue.*

Problem IV–B · How does Living Matter Differ from Nonliving Matter?

Living and nonliving things compared. Living things are made up of one or more cells which are composed of protoplasm. This fact, however, constitutes only one important difference between living and nonliving things, though it is probably related closely to all the other differences, such as those of form, size, structure, chemical composition, irritability, growth, reproduction, and movement.

1. *Form.* We are able to recognize dogs of any size as dogs, or trees of any size as trees, because they have the same general form. It is only because animals and plants look considerably like other animals and plants of the same kinds that we can tell the different kinds apart. Nonliving bodies cannot in most cases be distinguished by their shapes. Metals and most rock can be of any shape, and liquids and confined gases always take whatever shape the containing vessel may possess.

2. *Size.* There is an enormous difference in size between the microscopic living things and the greatest trees or the great animals, such as the whale and the elephant. Yet the size of any living thing is limited. This is not true of nonliving things. A rock may be an invisible grain of dust or a mountain; water may be an invisible particle of vapor in the air, or it may be all the oceans. Living things of the same kind, moreover, are usually limited in size. For example, full-grown men vary in size from less than four feet to more than nine; but the tiny men and the giants of fairy tales are creatures of the imagination only. The struggle for life is such that no animal or plant can vary greatly from the size which is most favorable to the survival of that particular kind of organism (Fig. 32).

3. *Structure.* All living things are composed of units called cells, each of which has a certain definite structure. Nonliving things have no unit of structure which is similar to the cell or which could even be compared with it.

4. *Chemical composition.* Living matter is usually composed of not more than ten of the ninety-two existing chemical elements, or simple substances. But all of the ninety-two elements are

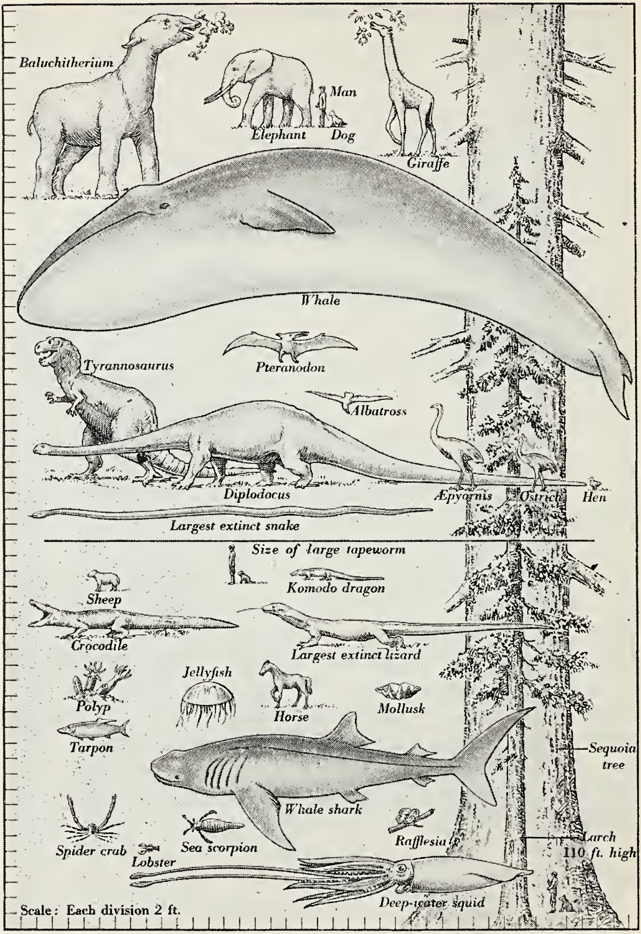


FIG. 32. These are the largest animals and plants of their kinds that ever lived on the earth. Are they ancient or present-day specimens?[1] The man, the dog, and the hen are added to give a basis for comparison of size

[1] After a drawing by L. R. Brightwell from Wells, Huxley, and Wells's *Science of Life.*

found in nonliving materials. Living substances (as will be explained later) are composed mostly of several elements in about the same proportions. Nonliving substances may be composed of only one element or of two or more elements in infinite variety.

5. *Irritability.* Living things are irritable; that is, they are all affected more or less by all sorts of stimuli, or influences, in their surroundings, such as sights, sounds, and odors. Nonliving things are not affected by such stimuli. The various reactions of living things to stimuli are known as their responses (Fig. 33).

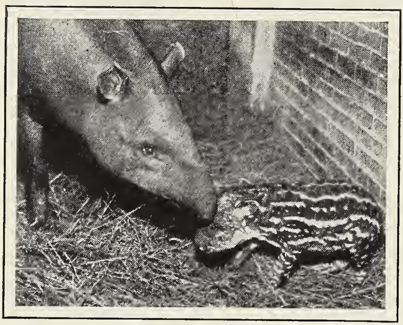
6. *Growth and change.* New material is added to every living part of a plant or animal. Nonliving objects can increase in size only by having more material added to them on the outside. Thus they do not really grow in the sense that plants and animals do. Similarly living cells are constantly breaking down, with the result that every living thing is constantly undergoing change in every part. Nonliving objects usually change only on their surfaces.

7. *Reproduction.* Living things produce young, which grow to resemble their parents. Nonliving things do not reproduce (Fig. 34).

8. *Movement.* Some living things are able to move about from place to place at will, and even those that remain anchored in one spot have movements of various sorts. Nonliving things have no such movements.

Fig. 33. How is irritability illustrated here? (Jasper National Park, Canada)

***Elements, compounds, and mixtures.**[1] Some facts about matter in general will help toward understanding the nature and activities of protoplasm. There are three classes of substances: elements, compounds, and mixtures. *An element* is a simple substance which cannot be broken up into any simpler substances. Thus oxygen or iron is always oxygen or iron and can never be anything else. The student of biology needs to know some of the characteristics of the common elements, such as oxygen, carbon, nitrogen, and hydrogen, which are especially important in the life processes of every living thing.



Newton H. Hartman

FIG. 34. A mother tapir and her two-day-old baby at the Philadelphia zoo. How does this picture illustrate reproduction, growth, and change?

Experiment 2. What are some of the characteristics of oxygen? Mix thoroughly three parts of potassium chlorate and one part of manganese dioxide which is thoroughly dry. [CAUTION: *Do not grind because of the danger of causing an explosion.*] Arrange the apparatus as in Fig. 35. Heat the mixture in the test tube by gently passing the flame back and forth over the test tube. After the gas has escaped from the tube for a few seconds, collect two or three bottles of it. Thrust a glowing wooden splint into one bottle of oxygen. Does the splint flame up, or is the glowing coal extinguished? The true color and odor of oxygen cannot be noted immediately after it has been collected in this way. These properties can be determined in Experiment 6. Summarize in a statement all the facts which you have learned about oxygen in this experiment.

Experiment 3. What are some of the characteristics of carbon? Collect several different samples of carbon, for example, a piece of coal,

[1] TO THE TEACHER. Much of the material included in the remaining pages of this chapter is discussed in all courses and textbooks of general science. It is here included to provide a desirable review for the pupils who have studied it earlier or to provide a necessary background for those who have not.

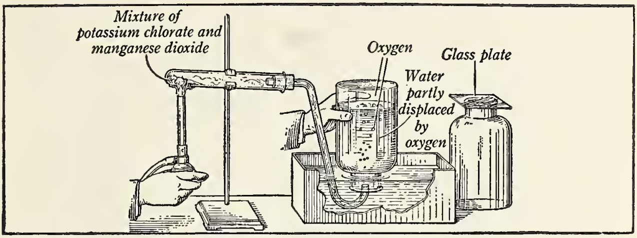


FIG. 35. Why is it better to collect oxygen over water than in air-filled bottles?

a piece of charcoal, and some soot deposited upon a cold dish from a candle flame. Can you succeed in burning each of the samples of carbon? Summarize in a statement the facts which you have learned about carbon in this experiment.

Experiment 4. What are some of the characteristics of nitrogen? If the oxygen is removed from the air, practically all that is left is nitrogen. To remove oxygen from air, place in a bottle cap as much red phosphorus as would equal the size of a pea. Float the bottle cap containing the phosphorus in a dish of water. Heat red hot one end of a nail or file, then with the hot end light the phosphorus. *Immediately* cover the bottle top with a jar (Fig. 36, *A*). [CAUTION: *Do not inhale the fumes of the burning phosphorus.*] The heat energy causes the phosphorus to combine with the oxygen in the air, forming a dense white solid substance like smoke. This slowly settles and dissolves in the water. What happens with respect to the level of the water in the jar as the powder dissolves in the water? When all the powder has dissolved, hold a glass plate *tightly* over the mouth of the jar under water and remove the jar from the dish of water. Set the jar right side up (Fig. 36, *B*). Keep the glass plate over the mouth of the jar, so that you may study the nitrogen. Note its color. Thrust a lighted splint into it. Does the wood continue to burn in the nitrogen? Summarize in a statement the facts about nitrogen you have learned from this experiment.

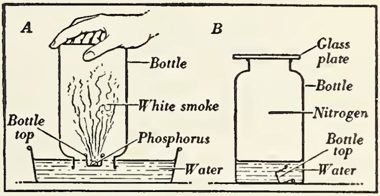


FIG. 36. Is the nitrogen thus obtained pure?

Experiment 5. What are some of the characteristics of hydrogen? Put into a flask some bits of zinc or powdered iron. Add a small piece of copper sulfate (blue vitriol). Arrange a thistle tube and a piece of bent glass tubing through the holes of a two-hole rubber stopper. Insert the stopper in a flask (Fig. 37). Attach to the end of the glass tube a length of rubber tubing sufficient to carry the gas generated in the tube to a pan of water, as in Experiment 2. Add dilute hydrochloric acid through the thistle tube until the end of the thistle tube is covered. Collect several bottles of hydrogen by the method used in collecting oxygen (Fig. 35). Keep the bottles upside down to prevent the hydrogen from escaping. Note the color of the hydrogen. Thrust a glowing splint into a bottle of hydrogen. Does the splint burn? Thrust a lighted splint into a bottle of hydrogen. Does the hydrogen burn? Summarize in a statement all the facts that you have learned about hydrogen from this experiment.

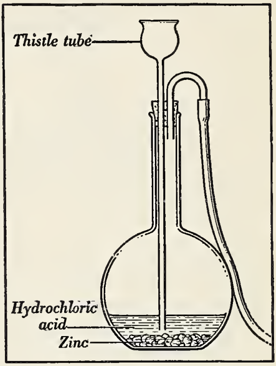


FIG. 37. Securing hydrogen for study. Why must the lower end of the thistle tube in this hydrogen generator be in the acid?

Elements are composed of minute particles called atoms.[1] One or more atoms make up a molecule, which is the smallest part of a substance that can exist by itself. No molecule is large enough to be seen even with the most powerful microscope. Sometimes energy is used in certain ways to cause the combining of two or more elements to form a *compound.* At other times energy is released or given off when new compounds are formed. When hydrogen is burned in oxygen, the compound hydrogen oxide, or water, is always formed. When carbon, such as coal or charcoal, is burned in oxygen, carbon dioxide is always formed. The atoms of hydrogen and oxygen in the first case have united to form molecules of water, each of which contains two atoms of hydrogen and

[1] Each atom is made up of one or more positive protons and one or more negative electrons. You will find more information about molecules and atoms in a textbook of physics or chemistry.

one of oxygen. The atoms of carbon and oxygen in the second case have united to form molecules of carbon dioxide, each molecule of which contains one atom of carbon and two atoms of oxygen. Similarly compounds can be made to unite with other compounds to form more complex compounds. Since water and carbon dioxide are of such great importance in the study of biology, it is desirable to learn some of the properties of these compounds by a study of them.

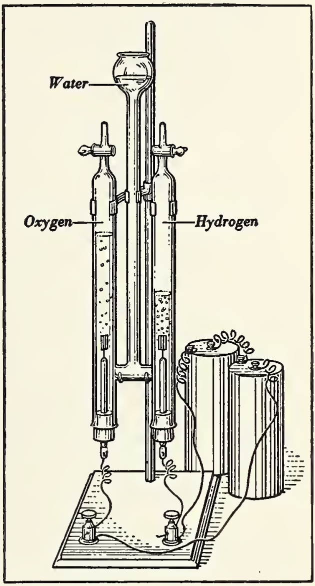


FIG. 38. What compound is here being broken up? Into what elements?

Experiment 6. What are some of the characteristics of water? To about a quart of water add a little sulfuric acid. Open the pet cocks (at the tops of the two side tubes of the apparatus) and pour the water into the middle tube until both the smaller tubes are full. Close the pet cocks. Connect the apparatus with two dry cells (Fig. 38). What happens in the two side tubes? The electrical energy breaks up the water molecules into atoms of oxygen and atoms of hydrogen. Since the water molecule is composed of two atoms of hydrogen and one of oxygen, twice as much hydrogen as oxygen is produced. When the hydrogen tube is nearly full, try to light the hydrogen as you cautiously open the pet cock. If it lights, quickly extinguish the flame to prevent the breaking of the tube by the heat of the flame. Put a glowing splint above the oxygen tube and cautiously open the pet cock. Do the hydrogen and the oxygen behave toward the flame and the glowing splint as they did in Experiments 2 and 5? Compare the color of the hydrogen and the oxygen with that of the water. Observe whether oxygen or hydrogen has an odor. From this experiment would you conclude that water is an element or a compound?

Experiment 7. What are some of the characteristics of carbon dioxide? Place about a tablespoonful of soda in a tumbler. Add enough vinegar, lemon juice, or other acid to cause violent effervescence, or bubbling. The gas formed is carbon dioxide. After a few seconds note the color of the carbon dioxide in the top of the tumbler. When the effervescence stops, dip a glass rod into limewater; then immediately thrust the wet end of the rod into the carbon dioxide in the tumbler. What color does the limewater on the rod become? Thrust a glowing splint into the carbon dioxide. Does the splint light? What happens? Thrust a lighted splint into the carbon dioxide. What happens? Summarize in a statement all the facts you have learned about carbon dioxide from this experiment.

Every molecule of water is exactly like every other molecule of water. And every molecule of carbon dioxide is exactly like every other molecule of carbon dioxide. No two different substances contain exactly the same combinations of atoms in their molecules. Therefore the number and kinds of atoms in the molecule of a given substance determine what the substance is.

Sometimes elements and compounds exist together without uniting to form new compounds. They are then said to be a *mixture.* A common mixture is air, nearly 80 per cent of which consists of the element nitrogen, and about 20 per cent of the element oxygen. It also contains small amounts of rare elements, among them argon and neon, and of compounds such as carbon dioxide, ammonia, and water vapor, together with nonliving dust particles, such as soot and soil, and living dust, such as bacteria, yeasts, molds, and microscopic animals. Other common mixtures are water, in which air is dissolved, and ocean water, in which common salt and various other substances are dissolved. No two portions of a mixture such as air would necessarily contain molecules all of the same kind, as would any two portions of an element or a compound.

Experiment 8. How can a mixture and a compound be made from iron and sulfur? In what ways do the mixture and the compound thus made differ? Make a small lump of sulfur into a fine powder. Add to the sulfur an equal quantity of iron filings. Mix the iron and the sulfur thoroughly. Hold a magnet near enough to the mixture to attract the iron filings. Can you separate the iron and the sulfur in this way? If this magnet test shows that the iron and the sulfur are

still separate substances, they have together made a mixture. Again mix the iron and sulfur. Heat the mixture in a test tube. When the contents of the tube begin to glow brightly, remove the burner and allow the contents to cool. Break the test tube and examine its contents. Can you see anything now which looks like either the iron or the sulfur? Does the magnet attract any of the material now? Summarize the results of this experiment by putting in each of the blanks either the word *mixture* or the word *compound*. By means of the heat energy the __(?)__ of iron and sulfur was changed to a ___(?)___.

Organic and inorganic matter. An understanding of facts about matter aids in a further understanding of protoplasm. What life itself is nobody yet knows. Many scientists have attempted to find out by analyzing protoplasm. But attempts to analyze it always kill it. Chemists have learned, however, what substances compose protoplasm. They have found it to be made up chiefly of the elements carbon, hydrogen, oxygen, nitrogen, and sulfur. It also contains smaller quantities of the elements phosphorus, potassium, calcium, magnesium, iron, and several others (Fig. 39). These elements are known to be combined in compounds. Some of these compounds, like water and carbon dioxide, are simple, having few atoms in their molecules. Others are exceedingly complex, containing in their molecules thousands of atoms. Most of the compounds in protoplasm, however, are composed of combinations of the four elements carbon, hydrogen, nitrogen, and oxygen.

*Having learned what substances compose protoplasm, many scientists have attempted to make protoplasm. Such attempts have always failed. They have succeeded in building up in their laboratories many of the compounds found in living things, but there their success has ended. They have failed in organizing the compounds so that a living thing has resulted. The compounds existing in protoplasm are organized in such ways as to carry on life. For this reason animals and plants are called organisms; their parts which perform certain necessary work in the division of labor are called organs; and living material and its products, together with dead animal and plant material, are called organic matter. All other matter, of whatever sort it may be, is called inorganic matter. Because they are so large a part of

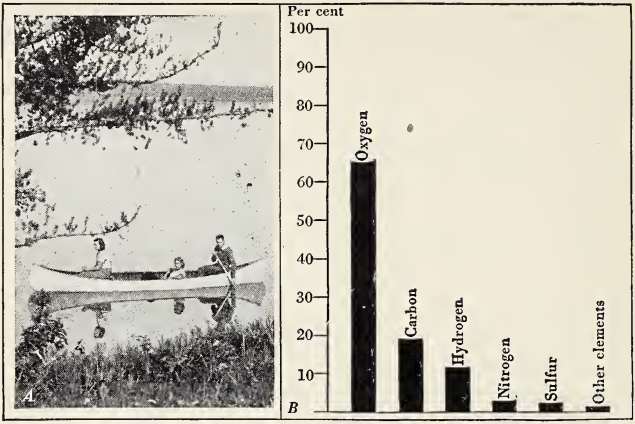


Fig. 39. What matter is organic and what inorganic in *A* (Prince Albert National Park, Canada)? What objects are composed of protoplasm? *B* shows the relative percentages of elements composing protoplasm. What per cent, respectively, are carbon, hydrogen, nitrogen, and sulfur? What elements are included in "all others"?

organic matter, compounds of carbon, oxygen, and hydrogen are called organic compounds. One great branch of chemistry, known as organic chemistry, is devoted to the study of such compounds.

Self-test on Problem IV–B. **1.** Name eight respects in which living things differ from nonliving things. Explain each.

2. Match each item under B with one item under A.

A	B
Organism	A colorless gas which causes rapid burning
Nitrogen	Water
Element	A colorless gas which constitutes most of the air
Phosphorus	Smaller than any cell but larger than an atom
Mixture	The same general name given to each of the ninety-two simple substances
Atom	A dead tree
Molecule	A living tree
Organ	
Oxygen	
Inorganic	
Hydrogen	

3. Which of the following are organic, and which are inorganic substances: gold, hair, marble, milk, ground-bone fertilizer, elephant's tusk, manure, limestone fertilizer, living dust, nonliving dust, wood, glass?

Problem IV–C · What are Some Important Chemical and Physical Processes which are Related to Living Things?

Oxidation. The student of biology needs an understanding of oxidation in order to be able to understand the life processes of plants and animals.

Experiment 9. When oxygen combines with another substance, is energy given off? Secure several bottles or jars with a glass plate to cover each. In the first place a short length of candle. Light the candle, place the plate over the mouth, and observe what happens. Put a small lump of sulfur in a bottle cap and place it in the second. In the same way place in the third a little red phosphorus held by a bottle cap. Light the sulfur and the phosphorus by touching them with the end of a file or of a large nail which has been heated red hot. Immediately place covers over the bottles containing the burning sulfur and phosphorus. [CAUTION: *Do not inhale the fumes from either bottle.*] Observe what happens. Light a loosely rolled ball of paper and drop it into a fourth bottle and cover it immediately. Observe. Light a wooden splint, drop it into a fifth jar, and cover it. Observe. Is the oxidation of the paraffin, the sulfur, the phosphorus, the paper, and the wood accompanied by a release of energy; that is, when each of these substances combines with the oxygen of the air, is energy given off? What kind of energy? When the oxygen within each bottle was all used up in the burning, did the energy continue to be given off? Answer with a complete sentence the question asked at the beginning of this experiment. Justify your answer.

Oxidation of food materials similar to that which has been illustrated in Experiment 9 is taking place constantly in all living things, as will be shown in later chapters. Such oxidation, however, is slow as compared with that in the experiment, though in all cases oxidation is accompanied by a release of heat energy and sometimes also by a release of light energy.

***Physical and chemical changes.** When energy is properly applied, both organic and inorganic substances are constantly undergoing changes. When the substance merely changes its

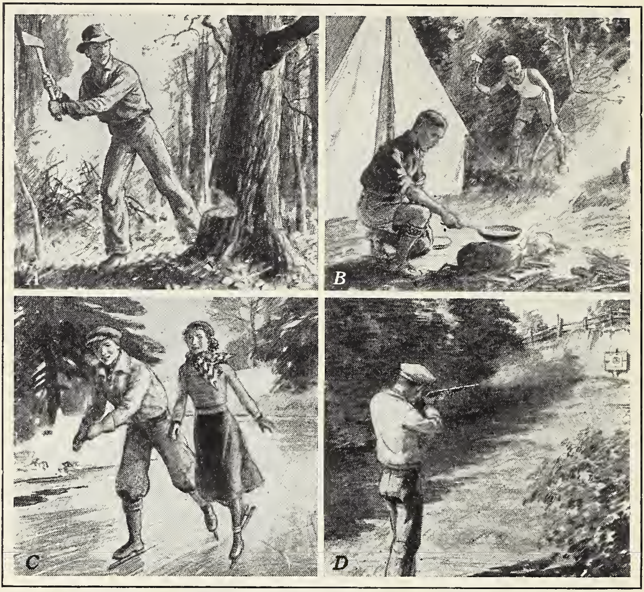


Fig. 40. What physical and chemical changes are illustrated in these four pictures?

form or its state, without changing the nature of its molecules, it is said to undergo a *physical change.* Thus cutting food into pieces small enough to get into one's mouth is an example of physical change, because the meat is still meat. When water is changed into ice or steam, it has undergone a physical change, because it is still water; that is to say, the molecules have not changed. Whenever the energy is applied, however, in such a way that the molecules are made to contain different numbers and kinds of atoms from those which they contained before, the substance is said to have undergone a *chemical change.* In that case the substance itself has been changed (Fig. 40). Thus the burning of fuel, the digesting of food, and similar changes which constantly go on in protoplasm are chemical changes.

Osmosis. Let us imagine that two gases, carbon dioxide and hydrogen, are put into a closed vessel together. Carbon dioxide is much heavier, volume for volume, than air; hydrogen is lighter, volume for volume, than any other gas. Hence the carbon dioxide would fall at once to the bottom of the vessel, pushing the hydrogen to the top. If, however, the two gases are left undisturbed, they will in time become equally distributed throughout the vessel. Similarly if two liquids which are capable of mixing are put together into a vessel, they will in time become equally distributed. Such mixing of gases or liquids is known as diffusion. Diffusion is explained as being due to the rapid independent motions of the molecules. These motions cause the molecules in time to become equally concentrated in every portion of the container.

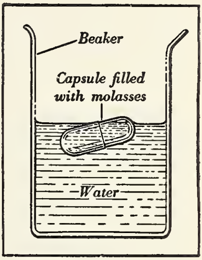


FIG. 41. How is osmosis illustrated here?

A process somewhat similar to diffusion may take place through the moist membranes of animal and plant cells. This process is called *osmosis.*

Experiment 10. What happens when different liquids are separated by a moist membrane? Secure from your druggist the largest empty capsule he has. This should be at least an inch long. Fill one half of a capsule with molasses or sirup, fit the other half on the first, and drop the capsule into water. The capsule represents a plant or animal cell, the molasses in it represents protoplasm, and the water represents fluids around the cell (Fig. 41). After about fifteen minutes examine the capsule. How have the contents of the capsule changed?

The results of this experiment may be explained thus: At first the molecules of water were more highly concentrated — that is, there were more of them per cubic inch — outside the capsule than inside. At the same time the molecules of sugar were more highly concentrated inside the capsule than outside. Therefore, as a result of their constant and rapid movements in all directions, the molecules of water tended to pass through tiny holes in the membrane from the outside, where they were more highly concentrated, to the inside. There was a similar tendency

for the sugar molecules to travel from their point of greater concentration, inside the capsule, to a point of lesser concentration outside the capsule. *Osmosis* may therefore be defined as the process by which liquids and gases travel through moist membranes from a point where their molecules are more highly concentrated to a point where their molecules are less highly concentrated. In this experiment the molecules of water and of sugar were going through the membrane at the same time and in opposite directions. The sugar molecules were larger and also moved more slowly than the water molecules. Hence the capsule gained water molecules more rapidly than it lost sugar molecules, and consequently became filled. If the process could have been allowed to proceed long enough, however, without destroying the capsule, the molecules of sugar and of water would finally have become of equal concentration on both sides of the membrane. There would then have been equal numbers of both water molecules and sugar molecules passing constantly into and out of the capsule.

Self-test on Problem IV–C. **1.** The burning of wood in air is an example of *respiration.*

2. Which of the following are elements, which compounds, and which mixtures: lemonade, iron, lead, smoke, beef, rock, wet sand, air containing much water vapor?

3. Tearing paper is an example of *physical* change.

4. Heating water is an example of *chemical* change.

5. Water enters plant tissues by the process of *oxidation.*

6. The breaking up of water into hydrogen and oxygen is an example of *chemical* change.

Self-test on Biological Principles. Explain and illustrate the meaning of this biological principle: "The cell is the unit of structure and function of all organisms."

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Can you state any reasons why tissues in different kinds of living things can never be exactly the same?

2. Explain why a vegetable stew is a mixture. How does concrete illustrate both a mixture and a compound?

3. The air over great cities is somewhat different from air over country districts or over desert or lake regions. Explain.

4. How many examples of physical and chemical changes occurring in nature can you name in three minutes?

5. Will dried fruit, such as prunes, swell more when cooked with sugar or when cooked without sugar? Explain.

Exercise on Scientific Attitudes. The names of Matthias Jakob Schleiden, 1804–1881, a noted German botanist, and Theodor Schwann, 1810–1882, a German physiologist, are always considered together because together they contributed the cell theory. Although they worked separately, they were fast friends and discussed their discoveries and conclusions together. Their work, especially that of Schwann, had great influence later upon the work of Pasteur and Lister. Which of the scientific attitudes (pp. 12–13) are illustrated by the work of Schleiden and Schwann? (Consult an encyclopedia for additional facts about these men.)

Special Report. Bring to class samples of the elements sulfur, phosphorus, and iron; and of the compounds potassium nitrate, sodium nitrate, potassium chloride, and phosphoric acid or calcium acid phosphate. Look up in textbooks of chemistry and of agriculture the importance of these substances to plants and to men and animals.

Reference Books[1]

Locy, W. A. Biology and its Makers. Henry Holt and Company, New York.
Wilson, E. B. The Cell in Development and Heredity. The Macmillan Company, New York.

[1] These are only two of many books that might be named because they furnish interesting and valuable information which supplements the material of this unit but which is not found in biological textbooks written for use in high schools. A list of biological books to read for pleasure is found on page 674.)

UNIT II · *Plants and the World's Food Energy*

PROBLEMS DISCUSSED IN THIS UNIT

In any direction in which one looks, the view will probably extend over millions of food factories. Wherever one walks, one is likely to step on thousands of them. One may not recognize these food factories as such; yet they are among the most important objects in the world.

If all these food factories should suddenly stop their work, the warfare which was discussed in Unit I would soon cease. There would soon be nothing and nobody left to fight. Man as well as all other living things of the earth would soon disappear. The factories are, of course, green plants. The major problems discussed in this unit are the following:

How are various kinds of green plants equipped to transform the sun's radiant energy into food energy?

How is the process of food manufacture carried on in green plants?

What are the characteristics of plants which make them successful organisms?

How are various kinds of plants equipped to compete for the sun's energy?

Chapter V · The Plant and Some of its Problems

Questions this Chapter Answers

In what respects is a green plant like a factory?

How are leaves of deciduous plants like and how are they unlike those of evergreen plants?

What are the nature and importance of photosynthesis and transpiration?

What materials are used by the green plant in making food?

What structures within the leaf are directly concerned with food-making?

How is energy secured for use in food manufacture?

What uses are made by the plant of the food which it manufactures?

What are some other important leaf functions?

Problem V–A · How is a Green Plant Equipped to Transform the Sun's Radiant Energy into Food Energy?

The green plant a manufacturing organization. In some ways a green plant is like a large manufacturing organization. Such an organization has separate divisions which manufacture desired products from raw materials. It has its own transportation system to carry raw materials to the factories and also to carry finished products from them. It has its warehouses in which the surplus manufactured products are stored until needed. In a green plant each leaf is a separate factory engaged in the manufacture of food. Certain tissues which are in the leaves, branches, stem, and roots permit the circulation of sap. These tissues compose the transportation system. The various parts of the plant where surplus food is stored are the plant's warehouses. Every part of the plant organization is in some way necessary to the other parts, but each part has its own special uses. The following pages discuss not only the structures of the various parts of the plant organization, but also the ways in which they do their work and contribute to the welfare of the whole organism.

The leaf crop of one season. During winter, in the temperate zones, some of the shrubs and trees, such as maples, elms, and

Fig. 42. Compare the deciduous trees in *A* with the evergreen tree in *B*. (See "Suggestions for Effective Study," p. xvi)

fruit bushes and trees, have no leaves. Such plants are called deciduous, a word which means that such plants shed all their leaves regularly each autumn. Other trees and shrubs, such as hemlocks, spruces, fir, pine, yew, and cedars, and even smaller plants, as the rhododendron, laurel, some kinds of holly, and some of the ferns, shed their leaves a few at a time, and may retain some for several years before shedding them. Such plants are called evergreens, since, as long as they live, they are never without some of their green leaves (Fig. 42).

Deciduous and evergreen plants both produce new leaves each year. These new growths are not so commonly observed on the evergreens as on deciduous plants, because the new leaves of evergreens are added to the green leaves which the plants already possess, while the new leaves of deciduous plants appear upon branches that were bare.

In tropical countries, just as in the temperate zones, new crops of leaves are produced regularly. This new crop of leaves is less conspicuous in the tropics than in the temperate zones because, in the tropics, so many more of the trees and shrubs are evergreen. The sudden appearance of an almost wholly new supply of leaves

FIG. 43. Explain these three stages in the development of a bud

is one of the most pleasing features of springtime throughout the temperate zones. In the temperate zones the evergreen plants are mainly those that have narrow and rigid leaves. In the tropics some of the evergreen plants have narrow leaves, and some have broad leaves.

Each green plant, in order to survive, must have sufficient leaves to produce the food energy it needs for growth and reproduction. A deciduous tree or shrub usually produces a new crop of leaves in a very short time. This rapid growth is of advantage because it enables the plant to make the best use of the few months in which it has leaves. The plant, especially if it grows in the temperate zone, may have been dormant[1] for six months before the leaves appear.

The sunny and warm days of spring serve to start the opening of the buds, which in many plants were formed at the close of the preceding season. In a week or ten days, fewer for some plants and more for others, the buds have opened, and the clusters of new leaves have emerged (Fig. 43). After two or three more warm days the leaves have gained full size. The portion of the branch which bears the leaves elongates[2] so rapidly that, within the first warm period of the season, almost the entire crop of new leaves may be ready to engage in food-making. Some other kinds of plants continue to produce new leaves throughout most of the growing season.

[1] *Dormant* (dor′mant): not active; in a state which resembles sleep. *Dormancy* (dor′man sy): the condition of being dormant.

[2] *Elongate* (e lon′gate): to grow long rather than wide; to grow to be long and narrow. *Elongation* (e lon ga′shun): act of elongating, or lengthening.

***Inside the leaf factory.** The most conspicuous parts of a leaf are the blade and its veins, and sometimes the leaf stem, called the petiole. The manufacture of food takes place in the blade. The transportation of materials to and from the leaf factory is carried on through the veins (Fig. 44).

FIG. 44. This cottonwood leaf was placed in water where one-celled animals (*Euglena*) ate the chlorophyll tissue but not the upper epidermis or the veins. What are the functions of the epidermis and the veins?

*The cross section of a leaf (Fig. 45) shows a number of important parts in more detail. The outside layers of cells compose the epidermis.[1] In parts of the epidermis are special openings called stomata.[2] Each stoma is guarded by two cells, called guard cells. Under certain moisture conditions these guard cells may change their forms so as to open or close the stoma, thus controlling the amount of air which may enter and pass out of the leaves. Each stoma opens into a large space among the inner green cells of the leaf. These spaces permit the food-manufacturing cells to secure needed gases from the air and to give off the waste products into it.

Experiment 11. Are there more or fewer stomata in the upper epidermis than in the lower epidermis of a lily, geranium, maple, elm, or other common leaf? Carefully peel off the epidermis only, from the upper and lower sides of the leaf. Mount the two specimens on a microscope

[1] TO THE TEACHER. For the structure of the epidermis, the pupils may be referred to Experiment 1, p. 50 (epidermal cells of an onion).

[2] *Stoma*, plural *stomata* (sto'ma ta): openings in the surfaces of leaves. Sometimes the words *stomate* and *stomates* are used as the singular and plural, but *stoma* and *stomata* are preferred.

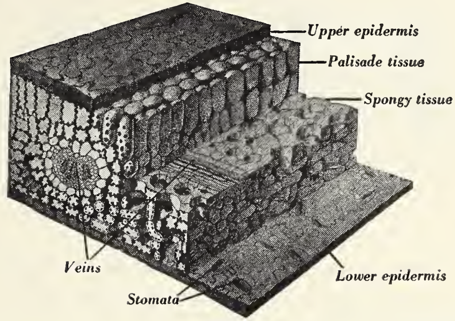


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Fig. 45. Explain the functions of the various leaf structures shown in this diagram

slide and examine them under the low power of the microscope. Make a complete statement or make diagrams giving the results of your observations. Examine the stoma under the high power and compare what you observe with Fig. 45. Make sketches of any types of stomata which seem to be different from those shown in Fig. 45. What advantage does the plant derive from having its stomata distributed as you observed them to be?

The large inner cells of the leaf usually have two kinds of arrangement. Near the upper epidermis the cells are long and are placed side by side somewhat like the stakes or poles in a palisade.[1] For this reason these upper cells are called palisade cells. In the interior of the leaf and usually extending to the lower epidermis, the green cells are loosely arranged like the tissue of a sponge. This tissue is called the spongy tissue of the leaf. The palisade cells, and to a somewhat lesser extent the spongy tissue cells, are the chief food-making parts in the leaf factory.

*The palisade and spongy tissues are not wholly green, but they contain many small green bodies, called chloroplasts, or chlorophyll bodies. These are so small and so numerous that they cause the whole leaf to appear green. There are no chloroplasts, however, in the veins or in the spaces of the spongy tissue, and

[1] *Palisade* (pal i sade′): the high fence or wall made by driving stakes into the ground around a fort.

FIG. 46. Leaf scars. Can you determine where the veins or the vascular tissues continued from the stem into the leaf?

usually few or none in the cells of the epidermis. The guard cells, however, have chloroplasts. The chloroplasts are the bodies in which the plant's food is made.

The transportation system within the leaf. When a leaf is carefully pulled from the stem or branch which bears it, one may usually observe the broken veins, or vascular[1] bundles. In many kinds of plants the scars that are left after the leaves are shed show the ends of the vascular bundles (Fig. 46). The midrib and veins of the leaf are units in the transportation, or circulatory,[2] system of the plant which connect with the transportation structures in the stem and root. In a cross section of a leaf (Fig. 45) the midrib and veins are seen to consist of cells which have thick walls and small cell spaces between the walls. These cells, which in cross section appear relatively small, are really like cylinders and are long and tubular.[3] These groups of cells are called vascular bundles, or fibrovascular bundles, both because the cells are in bundles, or fibers, and because they are used in the circulation of sap.

Self-test on Problem V–A. 1. The spruce or the fir is an example of *an evergreen* tree.

2. The apple tree or the oak is an example of *a deciduous* tree.

3. Evergreen trees shed *none* of their leaves each year.

[1] *Vascular* (vas'ku lar): made up of tubes and ducts, or vessels, and having to do with the circulation of blood or sap.

[2] *Circulatory* (sur'ku la to ry): having to do with circulation, or flow, as of sap in plants or blood in animals.

[3] *Tubular* (tu'bu lar): shaped like a tube, or cylinder.

4. *Deciduous* trees are usually dormant during the *summer.*

5. The *chlorophyll* of green plants is the means by which plants directly and indirectly manufacture all the food in the world.

6. Most of the food is manufactured by the cells of the leaf *epidermis.*

7. Water used in food manufacture enters the leaf through the *stomata.*

8. The waste products resulting from food manufacture in the leaves are given off through the *petioles.*

9. The green bodies which manufacture the food in plants are called *chloroforms.* These are located mostly in the *veins.*

10. Liquids are transported to and from the leaves through the *palisade tissues.*

11. Try to define in your own words (1) petiole, (2) epidermis, (3) stoma, (4) chloroplast, and (5) vascular. Compare your definitions with those given for these terms in the Glossary.

Problem V–B · How does the Green Plant Manufacture Food?

The raw materials used in the leaf factory. The water which comes into plants from the soil carries many soil substances in solution. Such solutions are formed when the molecules of soil materials become distributed among the molecules of water. Soil substances include (1) compounds that have been left in the soil by the decay of plants and animals that once lived; (2) nitrogen compounds produced by certain soil bacteria; and (3) special plant-fertilizers that have been placed in the soil by the farmer or gardener. Such soil substances are composed chiefly of (1) compounds of nitrogen and oxygen which are called nitrates; (2) compounds of sulfur and oxygen called sulfates; (3) compounds of phosphorus and oxygen called phosphates; and (4) such other compounds as those of oxygen with sodium, with iron, with potassium, with calcium, and with magnesium. Still other compounds, some of which the plant cannot use, may enter the roots with the water which has dissolved them. Some of the dissolved compounds pass upward all the way to the leaf. They, together with the water from the soil and carbon dioxide from the air, are the necessary raw materials for the process of food-making.

Gases may enter the plant to some extent in solution with the water or they may pass through the bark, but gases enter and leave the plant chiefly through the stomata of the leaf.

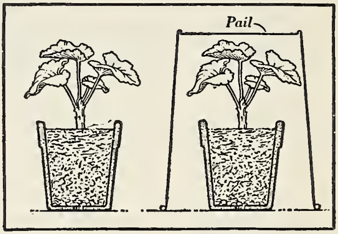

FIG. 47. Why is it a better scientific method to make the test with several leaves than with only two?

The food-making process. *Experiment 12.* Is more food produced in green leaves after they are placed in bright sunlight or when they are in darkness? Place two vigorous plants, such as geranium, coleus, or primrose, side by side in the bright sunlight. Cover one of the plants with a pail or other covering which will completely exclude the light (Fig. 47). After several hours take several leaves from each plant. Mark the leaves from each plant so that you will know from which plant they were taken. Place all the leaves in a beaker or test tube half full of alcohol, and then stand the beaker or test tube in warm water. The warm alcohol will remove the chlorophyll, or green material, from the leaves. When the leaves are as nearly white as they will become, remove them from the alcohol and pour over them a solution made by dissolving iodine crystals in either water or alcohol. If starch is present in any of the leaves, the leaves will turn blue-black. Answer the question asked at the beginning of this experiment.

Exercise on scientific method (using controls and isolating[1] the experimental factor). What conditions were the same with all the leaves? What condition was different? This was the experimental factor. The leaves which were kept in the darkness were the controls.[2] Why was it better to experiment with but one variable[3] factor, that is, with presence or absence of light?

Experiment 13. Are portions of leaves which contain no chlorophyll able to manufacture food? Place in bright sunlight a potted plant with variegated leaves, for example, a spotted begonia, a coleus, or a variegated geranium. After a few hours pick several of the leaves.

[1] *Isolate* (i'so late): to put by itself, or away from others of its kind.

[2] A control in an experiment is anything in the experiment which gives a basis for comparison. Every factor in the control is exactly like that in the experiment itself except one. This one factor, which is different, is called the *experimental factor*.

[3] *Variable* (va'ri a bl): having a tendency to change, or vary.

Test for starch, as in Experiment 12. Do the white parts of the leaf, which contain no chlorophyll, have starch? Do the green parts, which contain chlorophyll? From the experiment would you conclude that the plant does or does not need chlorophyll in order to manufacture starch?

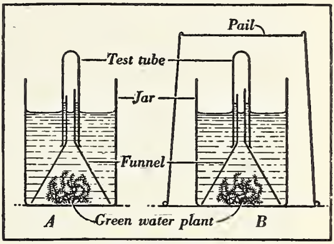

Fig. 48. Sunlight is the experimental factor. Explain

Check experiment. Place a growing geranium or other potted plant in the dark and allow it to remain there for several days until its leaves are white or yellow. Remove some of these leaves and see whether you can remove the chlorophyll from them, as in Experiment 12. Do they contain chlorophyll? Now place the plant in bright sunshine for a few hours. Test some of the leaves for starch. What results do you obtain from these tests? What conclusions, therefore, do you draw from this experiment?

Exercise on scientific method (using a check experiment and using controls). What is the value of a check experiment? In Experiment 13 the white spots on the leaves were controls. Explain.

Experiment 14. Does a green plant when placed in bright sunlight give off a gas? If so, can we determine what the gas is? Select vigorous green water plants of the same kind and as nearly alike as possible. Fill two jars with water to the same depth in each; then set up a carbon dioxide generator. (The carbon dioxide generator is made exactly like the hydrogen generator (Fig. 37, p. 60), except that soda or marble chips are used in place of the zinc.) Allow carbon dioxide to bubble for five minutes into the water of each jar. Then place a plant in each jar and cover each with a funnel. Over the top of each funnel place a test tube full of water (Fig. 48). Cover one of the jars completely with a pail or black cloth, so that it is entirely in the dark. Place both jars side by side in the bright sunlight. After several hours examine the test tubes over each plant to see whether either or both contain a gas. If so, test the gas with a glowing splint for oxygen and carbon dioxide.

Repeat the experiment exactly as at first, except that you expose the plant in vessel *B* to the sunlight and keep that in vessel *A* in the dark. Make a complete statement answering the two questions at the beginning of this experiment.

Exercise on scientific method (isolating the experimental factor, using controls, and making hypotheses). In the two parts of the experiment how many conditions were the same with both plants? What condition was different? The covered plant was the control. Why was it necessary to have all conditions except one as nearly identical as possible with both the experimental plant and the control? What was the advantage in repeating the entire experiment with the experimental factor applied to plant *B* and with plant *A* as the control? If no gas was found in the test tube above either plant, would this prove that neither plant gave off a gas? Suggest one or more hypotheses (possible or probable explanations) which might explain why no gas appeared, even though it might have been produced.

Part of the small portion of the sun's energy which comes to the earth strikes rocks and bare soil or penetrates the water of oceans, lakes, and rivers. This energy serves to increase the temperature of these bodies, to evaporate water, or to produce other effects. When green plants are absent, the radiant energy is not known to be of any use in changing water, carbon dioxide, and other substances into nourishing food materials. Only a small part of the sun's energy which does strike the earth is caught by chlorophyll. Nevertheless that small part is the means by which all the activities of all living things are carried on.

*The chlorophyll of green plants, in ways only partly understood, absorbs some of the sun's radiant energy and makes that energy available for producing chemical changes in the substances within the plants. Inside the leaf carbon dioxide from the air and water from the soil are acted upon by the energy caught by chlorophyll and are combined into food substances. The process by which green plants, through the agency of chlorophyll, secure energy from the sun and by using this energy construct compounds which the plant can use as food is called *photosynthesis* (see Glossary). The food compounds most commonly recognized as the results of photosynthesis are sugar and starch.

In the process of photosynthesis the energy is needed in changing the simple compounds carbon dioxide and water into the more complex compounds sugar and starch (Fig. 49). In chemical changes such as this the more complex the compound that is formed, the more the energy that is required in producing it from

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FIG. 49. Cactus plants, Platt National Park, Sulphur, Oklahoma. Does photosynthesis go on in plants such as these?

elements and simpler compounds. The compounds that are made first in the leaf, possibly because they change so quickly, are so difficult to study that biologists and chemists have not yet found out just what all of them are. We know that organic compounds are made, that is, compounds of carbon, hydrogen, and oxygen. We know also that grape sugar, which is somewhat like ordinary sugar, is formed, and that later starch and other organic compounds may be formed. We know, further, that a large amount of oxygen is released as a by-product during the process of photosynthesis. Thus the oxygen supply upon which all living things depend is constantly being replenished as a result of photosynthesis.

The grape sugar and starch produced by the process of photosynthesis belong to the class of organic compounds called carbohydrates.[1] Carbohydrates may be used as energy foods by

[1] *Carbohydrate* (kar bo hy′drate): an organic compound made up of atoms of carbon, oxygen, and hydrogen, but differing from other organic compounds in having twice as many atoms of hydrogen as of oxygen, just as has water. Thus the chemical symbol of water is H_2O, which means that the molecule of water is made up of two atoms of hydrogen and one of oxygen. The chemical symbol of grape sugar is $C_6H_{12}O_6$, which means that the molecule of grape sugar is made up of 6 atoms of carbon, 12 atoms of hydrogen, and 6 atoms of oxygen. The chemical symbol of starch is $C_6H_{10}O_5$. Can you explain the meaning of the symbol of starch?

either plants or animals, and much carbohydrate food is so used. Both plants and animals also need still more complex foods, called fats and proteins. These are discussed later in Chapter XIII. They may be produced from carbohydrates by chemical processes carried on by the protoplasm of both plant and animal cells.

FIG. 50. Can you explain how the potato plant stores excess food in its underground stems?

Additional energy is used in the processes of making these very complex compounds from simpler organic compounds such as grape sugar and starch. Their final use in building protoplasm requires still more energy. Complex foods and protoplasm, therefore, represent large amounts of energy, all of which comes from the sun and is transformed through the work of chlorophyll and protoplasm.

Foods for use and for storage. Within the green leaves larger quantities of carbohydrates are made than the leaf is likely to need at once for its own nutrition and growth. The sugars that have been made are easily dissolved in the sap of the leaf. They pass through the cell walls by osmosis and reach the vascular tissues. Through these they pass downward to all parts of the plant. Some of these sugars may be used by any living part of the plant, and some may be used in making proteins. Part of the sugar may be changed into starch which is not easily dissolved by cell sap and therefore may be stored. Many wild plants, such as violets, jack-in-the-pulpits, and forest trees, and some of our most important cultivated plants, such as the potato, corn, and wheat, store large amounts of carbohydrate food as starch (Fig. 50). Thus while the food is transported in the form of sugar, it is usually stored as starch, though in fruits it is also stored as sugar. No doubt the same material may sometimes be changed from one of these to the other many times before it is finally used for energy or for making protein foods.

Protein food, as well as starch, may be laid away, or stored, for later uses. Much food is also stored in the form of fats and oils.

Summary. *Photosynthesis* is the process by which the chlorophyll in green plants changes water and carbon dioxide into carbohydrates by means of the sun's energy. Photosynthesis takes place almost wholly in the leaves. Water from the soil travels from the roots through the vascular bundles to the leaf. Carbon dioxide enters the leaf through the stomata (Fig. 51). Water and carbon dioxide are combined within the palisade cells and spongy tissue cells of the leaf to form the carbohydrates grape sugar and starch. Oxygen is a by-product of this chemical action. The oxygen passes, by osmosis, through the cell walls into the air spaces within the leaf, and thence through the stomata to the outside.

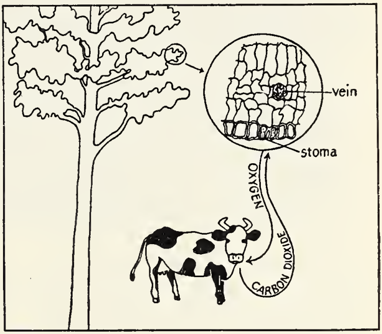

FIG. 51. This is a drawing by a high-school student of biology to illustrate the oxygen cycle.[1] Can you explain it?

Self-test on Problem V–B. **1.** Select from the following list the substances which enter plants through the roots: (1) water; (2) oxygen; (3) carbon dioxide; (4) sulfates; (5) compounds of phosphorus and oxygen; (6) chlorophyll; (7) compounds of oxygen and calcium; (8) protoplasm; (9) organic compounds; (10) nitrogen compounds.

2. The process by which green plants manufacture food with the aid of the sun's energy is known as (1) protoplasm; (2) phototropism; (3) poliomyelitis; (4) photostatic; (5) photoelectric; (6) proton; (7) phosphate; (8) photosynthesis.

3. Carbohydrates and fats are made of the elements __(?)__, __(?)__, and __(?)__.

4. Food is circulated throughout a plant in the form of *starch.*

5. Food is usually stored in plants in the form of *starch.*

[1] *Cycle* (si'kl): a series of stages which are repeated.

Problem V–C · What are the Nature and the Importance of Transpiration?

The water supply of plants. ***Experiment 15.***[1] Does water pass up through the stem and out of the leaves of a green plant? Select a leafy potted plant the stem of which is only slightly larger than the holes in a two-hole rubber stopper. Insert the stem in one of the holes of the stopper thus: Thrust through the hole, from the bottom of the stopper, a cork-borer or a glass tube which is slightly larger in diameter than the plant stem. Then insert the plant stem in the borer tube from the top. When you now remove the borer tube, the stem will be tightly fitted into the hole in the stopper. Fit into the other hole of the stopper a glass tube of the form shown in Fig. 52. Fill a bottle entirely full of water and insert the stopper tightly enough for some of the water to be forced almost but not quite to the end of the longer arm of the tube. There should be a small air space between the water in the tube and the level of the water in the flask. Watch the air space in the tube. What happens? Summarize your observations and conclusions in a few sentences or by means of diagrams. Now lift the tube from the flask so as to admit a little air into the long end of the tube. Before replacing it in the flask strip all the leaves from the plant stem. Replace the tube in the water in the flask. The apparatus will now look as in Fig. 52, except that the plant will have no leaves. Watch the air space in the tube. What happens? Summarize your observations and conclusions in a few sentences or by means of diagrams.

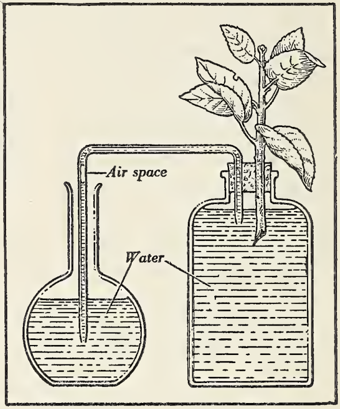

Fig. 52. **Exercise on Scientific Method (Using Controls): The plant, when stripped of its leaves, served as a control. Explain**

*Water is constantly passing into the air from green leaves. This particular kind of evaporation is called transpiration. All

[1] Adapted from an experiment suggested by Professor A. R. Sweetser.

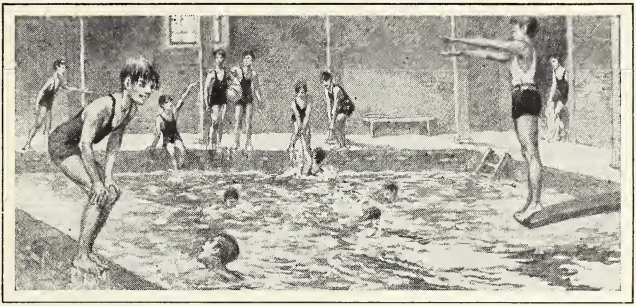

FIG. 53. The amount of water transpired by one and one-half acres of cabbages during the growing season of four months would fill this swimming pool, 60 feet long and 30 feet wide, to an average depth of $5\frac{1}{3}$ feet. One cubic foot of water equals 7.47 gallons. How many gallons of water are transpired by the cabbages in four months?

vegetation daily transpires[1] quantities of water so great that one cannot comprehend them. For example, an oak tree with about seven hundred thousand leaves transpires more than one hundred gallons of water daily during its active growing period (Fig. 53). It is believed that water is sometimes transpired and condensed again and again before it finally flows all the way down to the sea. Thus plant processes have an important part in making available the energy men gain in power plants from the use of running water.

The causes for the rise of water to the tops of the tallest plants are not yet fully understood. Imbibition — that is, the entrance of water into dead cells and into the microscopic pores and spaces in cell walls in much the same way that water rises in the pores of a blotter — is known to have some influence in sending water upward through plants. A more important influence is osmosis. By osmosis liquids from the soil enter the root hairs and the cells of the root epidermis and thence pass by the same process into the vascular bundles. The constant passage of water into the roots

[1] *Transpire* (tran spire′): to give off excess moisture. *Transpiration* (tran spi ra′shun): the process by which green plants give off excess water through the stomata of their leaves.

creates a pressure called root pressure, which tends to force the water upward. This root pressure is really osmotic pressure (see Glossary). From the vascular bundles of the smaller roots the liquids pass into those of the larger roots, those of the stem, and finally those of the branches and the leaves. In the leaves liquids pass by osmosis from the veins or vascular bundles into the leaf cells. From the moist surfaces of the walls of these cells water evaporates into the air spaces between the cells. When the stomata are opened by the guard cells, some of this moisture is transpired from the air spaces into the outer air surrounding the leaves.

Transpiration has an important influence upon the rise of liquids in the plant, because the evaporation of the moisture from the leaves decreases the amount of water in those cells. The greater osmotic pressure in the cells of the stem then forces water upward. The rise of liquids, however, is chiefly due to the tendency of small columns of water to hold together. Such threads of water in the vascular tissues may extend from the roots to the highest leaf cells. When osmotic pressure at the top is reduced by transpiration, the greater pressure below helps to push up these tiny threads of water. All these influences combined, however, — imbibition, osmosis, and transpiration, — are not sufficient to explain fully the rise of water to the tops of plants. Scientists have further problems to solve in explaining fully the ascent of water in plants.

The leaf factory closes. In temperate zones the period of favorable weather for photosynthesis is usually three or four months. It may be shorter or longer in different years. In the cases of many small plants all the activity of the chlorophyll for the entire year is completed in a few weeks. Spring beauty, crocus, dogtooth violet, and many other small plants produce their flowers, do their leaf work, and disappear. Some lie dormant underground until the next growing season. In order to survive, such plants must secure their energy, do their work, and get out of the way before the larger plants develop sufficiently to overshadow them.

By the dropping of the leaves the evaporating, or transpiring, surface of plants is greatly reduced. Deciduous trees and shrubs prepare to drop their leaves by forming a layer of hard-walled cork cells at the base of each leaf. This layer serves to cut off the leaf from the twig or branch on which it grows. Before this layer

of cells is formed, most of the food and living substance of the leaf is withdrawn into the other parts of the plant. When the chlorophyll is less active and while preparation is being made for shedding the leaves, striking colors often appear. These are not caused by frost, as is sometimes said, but are regular developments as part of the chemical and physical changes related to shedding the leaves when their work is done.

The evergreen trees do not prepare for winter by shedding all their leaves, as do the deciduous trees, though they have been losing some of their older leaves throughout the season. They are in less danger from excessive transpiration than broad-leaved deciduous trees would be, because their leaves are smaller and narrower. Moreover, their leaves have a smaller number of stomata. As autumn advances, however, evergreen trees are protected against harmful evaporation by a thickening of the leaf covering and by a closing of the stomata with a waxy secretion.[1] The next year the evergreens will not have to produce all their leaves anew. However, they will have smaller chlorophyll surfaces for their season's work than the deciduous plants, which produce a wholly new set of broad and actively working leaves.

***Summary of leaf functions.** The discussion of leaves has thus far dealt chiefly with photosynthesis and the closely related process of transpiration. These processes are, however, only two functions of leaves. Another important function in addition to (1) food-making by photosynthesis and (2) transpiration is (3) respiration, a process which will be discussed later. Certain leaves, moreover, may be adapted to performing special functions such as those of (4) protection (spines, thorns, and bud scales); (5) food storage; (6) water storage; (7) attaching (by tendrils) the plant to a support; (8) even in some cases adding to the food supply from photosynthesis by capturing insects for food. These various functions will be discussed in later parts of this book.

Self-test on Problem V–C. 1. Evaporation of water from green leaves is called *perspiration.*

2. Water is forced to the tops of plants as the result chiefly of three processes: __(?)__, __(?)__, and __(?)__.

[1] *Secrete* (se krete′): to form a new substance from body fluids, such as sap or blood. *Secretion* (se kre′shun): a special substance secreted usually by a gland.

3. Transpiration results in differences of *pressure* between the tops and the roots of the trees.

4. *All* deciduous plants carry on the process of photosynthesis during the entire spring and summer.

5. Trees lose *more* water by transpiration after they have dropped their leaves than before.

6. Evergreen leaves in general transpire less moisture than deciduous trees because (1) __(?)__ and (2) __(?)__.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Discuss photosynthesis (see "Suggestions for Effective Study," p. xv).

2. Why is it that more trees are blown down in heavy winds during summer than during winter?

3. Explain how transpiration and precipitation, or rainfall, compose a cycle.

4. Why do the evergreen trees need a less abundant supply of leaves than the deciduous trees during the active growing season?

5. If a tree or a shrub is pruned too closely, it will die. Explain.

6. The upper epidermis of leaves usually is thicker than the lower epidermis. Why?

7. When a shrub or tree is to be transplanted, the leaves are trimmed off rather closely. Why?

8. If early in the spring there is an unusually warm period followed by colder weather, deciduous trees or shrubs may be killed. Explain.

9. Does sprinkling leaves with water help the plant to secure the moisture it needs? Explain.

10. In what respects should you expect a leaf which has grown vertically, as that of iris or tulip, to differ from one which has grown in a horizontal position?

11. On which surface of a water-lily leaf should you expect to find the greatest number of stomata? Why?

Project 2. To make a study of the stomata and their arrangement and distribution on various kinds of leaves. Secure a number of different types of leaves, from deciduous shrubs, weeds, water plants, and the like. Prepare microscope slides of the upper and lower epidermis of each leaf. Make sufficiently numerous and accurate sketches to indicate clearly any differences which you observe in the stomata themselves or in their distribution on the various leaves.

Chapter VI · Different Structures for Different Uses

Questions this Chapter Answers

What is the general structure of stems?
What are the important differences between the stems of different groups of plants?
How do stems increase in length and in thickness?
What are the most important functions of stems?
In what ways are plant stems used by men?
What are the important structures and functions of roots?
In what ways are leaves, stems, roots, seeds, and fruits used as storehouses of energy?
What purposes are served by the food which plants store?

Problem VI–A · What are Some of the Structures and Functions of Plant Stems?

Stems differ in appearance. A California sequoia tree may have a stem more than two hundred fifty feet long and strong enough to support many tons of weight. A dandelion in contrast has a stem so short that it merely connects the leaves and roots. The stem of a wild grape may be more than a hundred feet long, but it is held up by trees, upon the stems of which it climbs. The stem of a pumpkin plant or watermelon plant, though sometimes very long, lies directly upon the ground. There is a wide variety in the kinds and forms of stems (Fig. 54). Yet all perform the necessary functions of stems, upon which the life of plants depends.

***The general structure of stems.** Not only do different kinds of plants have different kinds of stems, but young stems also differ somewhat from old stems of the same kind of plant. Yet all stems have certain structures in common. The outer layers of an older stem make up the bark. This bark is composed chiefly of dead cells built up from the inner cell layers. The outer layer of a very young stem is the epidermis. It consists usually of a single layer of slightly elongated cells. As the stem develops, more cells

are produced within, the epidermis hardens, and finally the bark is formed. The principal functions of the epidermis and the bark are (1) to protect the plant from too great loss of water; (2) to protect it from insect attacks; (3) to protect it from other injuries. Inside the epidermis of the growing stem is the cortex region, composed of several kinds of tissues. Some of these tissues give the stem strength. Others contain chlorophyll and can carry on photosynthesis. Deeper within the stem are the woody bundles known as vascular bundles. The vascular bundles may be scattered throughout the pith[1] or they may inclose the pith, depending upon the type of plant.

Fig. 54. In what ways do the grape stems depend upon the tree?

*The vascular bundles of the leaves are the veins. These are continuous with the vascular bundles in the outer part of the stem and extend downward into the roots. Thus there is a continuous line of vascular bundles from the roots through the stem and the branches into the leaves. The arrangement of vascular bundles produces two distinct types of stem structure. In one type the vascular bundles are arranged as a complete ring about the central cylinder of the stem. In the other type the bundles are scattered throughout the pith of the stem. The first type, having stems with woody vascular cylinders, is common in most of the trees, both deciduous and evergreen.[2] This type is

[1] *Pith:* the dead cells composing the central cylinder of a plant stem.

[2] The evergreen trees have vascular growth rings, as do deciduous trees. However, they have much more complex woody tissues, which are not discussed here. These trees belong to a group of seed plants called gymnosperms,

characteristic of the dicotyledons,[1] or dicots, most commonly illustrated by such plants as beans and sunflowers and by oak, hickory, walnut, and other nut-bearing trees.

The second type of stems, in which the vascular tissue is scattered, includes the seed plants known as monocotyledons,[2] or monocots. Common illustrations of monocotyledons, or monocots, are corn, lilies, and the grasses. The names *dicot* and *monocot* refer, not to the stem structures, but to the number of leaves found in the embryo[3] plants (Fig. 55). Monocots and dicots will be discussed further in Chapter IX.

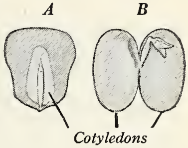

Fig. 55. Corn and bean seeds, showing cotyledons. Where is the embryo in each of these seeds?

Important differences in stems. ***Experiment 16.*** Through what parts of monocot and dicot stems do liquids move upward? Cut several living stems of such monocots as corn, lily, or narcissus, and of such dicots as young twigs of willow, maple, or apple. As soon as they are cut, place the cut ends in red ink or in a solution of eosin. On the following day remove the pieces of stems and cut off the parts that were submerged in the colored liquid. Examine the cut ends that were above the liquid to see if there are colored regions showing where the liquid passed up in the stems. Then cut the stems lengthwise to see how far the liquid passed upward. Note any differences in the location of these structures in the different types of stem. Summarize the results of your experiment in brief statements or by diagrams.

Exercise on scientific method (using controls). Why is it better to use several monocot and several dicot stems rather than only one of each kind?

Experiment 17. What are the arrangements of cells of vascular bundles in the stem of a monocot and of a dicot? Cut very thin cross sections

discussed in Chapter IX. The deciduous trees belong to a group called dicotyledons (see footnote 1, below), which, together with the monocotyledons (see footnote 2), compose the group of flowering or seed plants known as angiosperms.

[1] *Dicotyledon* (di kot i le′don): a plant with two seed leaves, or cotyledons. The two halves of a bean, pea, or peanut seed are the two cotyledons (Fig. 55, *B*). *Dicotyledon, dicotyl,* and *dicot* have identical meanings.

[2] *Monocotyledon* (mon o kot i le′don): a plant with one seed leaf (Fig. 55, *A*). The terms *monocotyledon, monocotyl,* and *monocot* have identical meanings.

[3] *Embryo* (em′bre o): a young animal in its earliest stages of development within the egg or a young plant within the seed.

of the twig and the cornstalk used in Experiment 16. Be sure that each section shows clearly the structures through which the liquids passed upward in the stem. Mount a very thin section both from the twig and from the cornstalk on a microscope slide and examine each through the low-power objective of the compound microscope until you locate one of the vascular bundles in each. Then shift to the high power of the microscope and examine the different cells carefully. Make a series of statements or of diagrams indicating the characteristics of the cells of the monocot and the dicot through which the red liquid passed upward.

If you have specially prepared slides of typical monocot and dicot stems, study them carefully after you have examined the slides you have made. Note the structure of the cells surrounding the vascular bundles and of the cells of the region at the outer edge of the stem. Compare what you observe with Fig. 56. Describe or indicate clearly by diagrams the differences you note between these cells and those of the vascular bundles, and also any differences you note in the cross sections and especially in the vascular bundles of the monocot and of the dicot. Your diagram or description of the dicot stem should clearly show the nature and the location of pith, wood, cambium, bark, and medullary, or pith, rays. Your diagram or description of the monocot should show the rind, or cortex, the pith, and the vascular bundles. Compare the vascular bundles you are observing with the figure of a cross section of a vascular bundle in a leaf (Fig. 45, p. 75).

*A vascular bundle consists of several kinds of cells. In the dicot bundle three of these kinds are especially important, and these three compose almost the whole bundle (Fig. 56, *B*). These are (1) the heavy-walled wood cells, called xylem (see Glossary) found on the side of the bundle nearest the center of the stem; (2) the thin-walled outer cells, called phloëm; (3) between the xylem and phloëm a layer of small thin-walled cells, called the cambium. Water passes upward in the stem through the cells of the xylem. Food materials pass from the leaves downward in the stem through the cells of the phloëm. Almost all growth of the plant in thickness is accomplished by division of the cells of the cambium.

In the monocot stem the vascular bundles contain xylem and phloëm for the passage of liquids upward and downward, as in the dicot, but only the very young bundles contain cambium tissue. This fact means that monocot bundles soon reach their

limit of growth. In the dicot bundle the cambium may continue to produce new phloëm and new xylem, sometimes for many years.

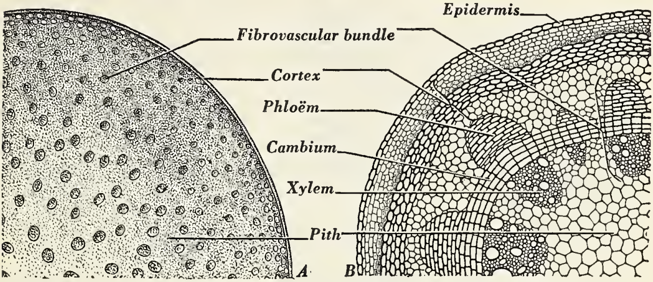

FIG. 56. Compare the monocot stem *A* with the dicot stem *B* (see "Suggestions for Effective Study," p. xvi)

The pith is in the center of dicot stems. It is not a part of the vascular bundles. After the pith has been formed, it does not increase in a stem. On the contrary, since the protoplasm of pith cells does not live long, the walls of pith cells become more and more compressed, so that in older stems the pith can scarcely be found.

Support by the monocot stem. The stem, or stalk, of corn illustrates the way in which any monocot stem is constructed. When such a stem is broken and one part carefully pulled away from the other part, threads, or fibers, are seen scattered through the pith at the broken surface. These are the vascular bundles. These bundles serve to conduct liquids but are not very important in giving support to the weight of the whole plant.

In a cross section of a cornstalk (Fig. 56, *A*) the vascular bundles nearest the outside are seen to be smaller and more compactly arranged. Outside the bundles and composing the surface of the stem are many thick-walled cells. It is this outside layer of cells, or the cortex, and not the vascular bundles, which provides strength and support for the corn plant. The pith cells, which compose most of the stem, are light and may hold moist air. The stem is stronger than it would be if the same amount of strong outer tissues were in a small, compact, and solid cylinder instead of surrounding the larger pith area.

Arrangement of parts in the dicot stem. In a dicot stem the pith is in the center. The vascular bundles are arranged in the form of a cylinder surrounding the pith (Fig. 56, *B*). In a very young dicot stem the bundles are separate, with the pith extending somewhat between the vascular bundles. As the stem grows, the bundles crowd closer together, so that only a small amount of pith is found at the center of older stems. Some pith cells may extend from the center toward the outer part of the stem, and these are called the pith rays. The pith in woody stems serves as storage tissue.

Self-test on Problem VI–A. 1. *All* stems have bark.

2. *No* stems have epidermis.

3. The different structures of the young plant stem, named in their order from the outside of the stem to the center, in general are *pith, epidermis, cortex, vascular bundles.*

4. The stems of *old* plants to some extent share with the leaves the process of photosynthesis.

5. Corn and the grasses are plants having *one* seed leaf, or cotyledon.

6. Beans and peas are plants having *one* seed leaf, or cotyledon.

7. The *cambium* layer serves as the means of transporting liquids upward through the *stem.*

8. The *xylem* tissues serve as the means of transporting *liquids* downward through the stem.

9. The growing tissues of the plant are located in the *phloëm.*

10. The pith area of the dicot stem *increases* in size as the *stem* becomes older.

11. In the *dicot* stem the vascular bundles are arranged in the form of a cylinder, near the *center.*

12. In the *monocot* stem the vascular bundles are scattered throughout the *cambium* of the stem.

Problem VI–B · How do Stems Grow?

How stems increase in length. ***Experiment 18.*** Where are buds located on a stem? Examine twigs of several different kinds. Do you find buds (terminal buds) at the ends of the twigs? Do you find other buds (axillary buds) just above the place (Fig. 57) on the stem where the leaf is attached? Do you find buds (adventitious buds) at any

other points on the twigs? Can you find any bud scars or leaf scars? A ring of bud-scale scars shows where one year's growth ended and the next year's growth began. Can you find such rings? If so, can you determine how old the twigs are? Summarize your observations in a paragraph or by means of labeled sketches.

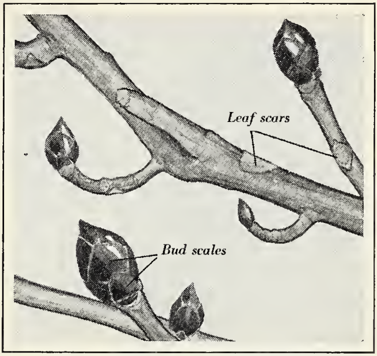

FIG. 57. Can you tell from a study of the scars whether this twig is more than one year old? Explain

Experiment 19. What is the structure of a bud? If this study is made during springtime, abundant illustrations may be collected out of doors. If the study is made in autumn or winter, illustrations may be secured from a greenhouse or by keeping dormant buds of trees and shrubs in jars of water in the classroom. Secure twigs, some having dormant buds and others having buds that are starting to open. By the use of a hand lens find what covers the bud and what parts can be found inside this covering. By comparison with a growing bud of which the new growth has become an inch or more long, determine what parts are present in both dormant and developing buds. What takes place in the process of growth from a bud? If it is available, study an unopened flower bud of a lily, an amaryllis, a pumpkin, or an apple. Compare the parts of the bud with the parts of an opened flower. Are all the parts of a flower present in the unopened bud?

*All green plants grow taller by the development of buds and by growth at the tips of the stems or branches. A bud is a very short piece of modified stem. In a monocot, which consists of a single stalk, both the leaves and the stem develop from the growing bud at the tip of the stem. In a dicot the leaf buds and branch buds usually form on the ends of branches or stems, though such buds (Fig. 57) develop also on the sides, usually just above a leaf scar. Within a leaf bud there is a short length of stem, the

extreme tip of which is the most actively growing point. The inside of the bud is protected by partly developed leaves that are folded tightly, and usually also by several layers of scales, which are modified leaves called bud scales. Flower buds usually develop on the sides of stems and branches in such plants as plum, apricot, gooseberry, cherry, and walnut. Such buds contain no leaves, but contain several scales and flowers. Mixed buds are found on certain plants, such as the persimmon, oak, apple, pear, blackberry, and grape. Such buds contain both leaves and flower parts.

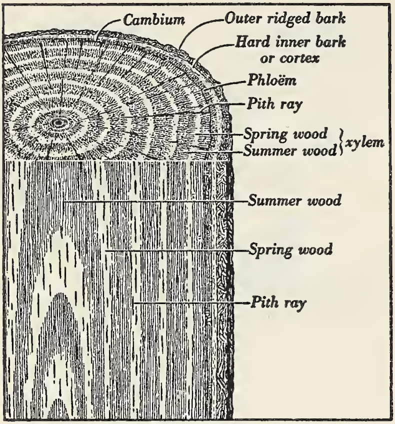

FIG. 58. What are the functions of the labeled parts of this diagram?

Buds may develop into new branches, or they may add to the length of an older branch. The nearer the end of a branch a bud is, the more active and rapid is its growth likely to be.

How stems increase in thickness. In monocots, as has been shown, the vascular bundles of very young stems contain cambium. This develops into xylem cells in the inside and phloëm cells on the outside, thus providing passageways for liquids, but new cambium tissue is not formed. The result is that mature monocot stems can grow thicker only by an increase in the number of vascular bundles and by an increase in the size of the xylem and phloëm cells. Most monocot stems that are old remain of about the same thickness because the number of their vascular bundles does not increase.

*In dicots the vascular bundles of young stems contain cambium, which forms not only new xylem on the inner side and new phloëm on the outer side but also new cambium between the xylem and phloëm. The result is that every bundle contains a

growing layer of cambium which is capable of adding to the thickness of the stem (Fig. 58). In dicots the newly formed xylem cells soon become like the older woody cells. The newly formed phloëm cells are thin-walled like the phloëm cells of the preceding year or two. Thus the dicot stem grows bigger in diameter in somewhat the same way as does a water wave caused by a pebble dropped into a pool.

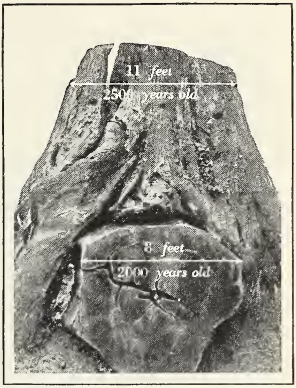

Fig. 59. The stem of the older of these two California redwoods fell, and at some later time the other tree began to grow upon the fallen tree. The ages of the two trees together totaled more than forty-five hundred years. How were the ages of these trees determined?

As the stem of the dicot grows in size the older phloëm cells are changed into the bark tissues. The outer bark consists of old cells having no living protoplasm. The walls of these cells have become pressed together so that even when magnified they are seen to bear little resemblance to the living cells they once were. Both the living and the dead layers of bark tissue are most useful in protecting and strengthening the stem. Sometimes in small stems chlorophyll develops in the inner bark, or cortex, and to some extent shares the work of photosynthesis with the chlorophyll in the leaves.

The inner dead xylem tissues are useful not only in conducting water upward in the plant but also in supporting the heavy weights of larger plants. Other groups of tubelike cells, called pith rays, medullary rays, or vascular rays, connect with the phloëm and the xylem. These carry water and food to tissues not sufficiently supplied directly by the xylem and phloëm.

In the early part of the growing season the cambium produces new xylem cells that are large. During the hot and usually drier summer weather the new xylem cells are smaller. The thickness of the cell walls and the small cell spaces together cause the summer wood to appear darker than the spring wood. This difference

in appearance makes it easy to count the number of yearly growth rings (Fig. 59). Such annual growth rings of woody tissue, of course, are found only in dicots and in such evergreen trees (gymnosperms) as spruce, hemlock, fir, and redwood. In unusual cases when a prolonged drought has occurred and is followed by favorable growing weather, trees may have a second growth period. In such rare cases it is possible for two rings of wood to be formed in a single year. This occurrence is so rare, however, that the growth rings are regarded as a fairly accurate indication of the age of a plant.

Experiment 20. How old is a stem? Cut a young stem of apple, maple, willow, or another dicot. Count the growth rings from the center to the outside. If each ring represents a year, how old is the stem? Answer in a complete sentence.

The xylem, phloëm, and cambium tissues are arranged in the form of a cylinder in the annual[1] dicots, as well as in perennials.[2] Outside the active phloëm of a perennial, layer after layer of bark is built. These layers add strength and protection to the stem, but do not carry food materials.

Development of annual additions of tissue makes it possible for woody dicot plants to rise high in the air and thus to place their leaves above other plants, to support enormous weights of branches and leaves, and to withstand exigencies[3] of various sorts. This annual growth habit of dicots and evergreen trees in their struggle for light has produced the enormous forests which supply timber for the lumber industries, pulp for the paper mills, and trees for shade and decoration, and which control to some extent the water supplies in the headwaters of streams. Only a very few monocot stems, such as the palms (Fig. 60), grow tall, and even their special supporting tissues do not make it possible for them to carry heavy tops like those of forest trees. Most monocots must live close to the earth, since their stems cannot lift their leaves high in the air.

[1] *Annual* (an′u al): pertaining to a year. An annual plant completes its entire life in one year.

[2] *Perennial* (per en′i al): continuing for more than one year. A perennial plant lives from one year to the next. Some perennial plants live for centuries.

[3] *Exigency* (ex′i jen sy): an unusual and critical occasion or situation.

***Summary of stem functions.** The preceding discussions have emphasized chiefly three important functions which the stem of every plant must serve. These functions are (1) to uphold and present the leaves to the sunlight so that food manufacture by the process of photosynthesis may go on; (2) to provide for transportation of raw materials to the leaves and of manufactured food materials from the leaves to all parts of the plant; (3) to provide for growth. There are other functions of stems, some of which have been mentioned and which will be discussed later. In the larger plants the stems (4) must also support themselves and the weight of their branches, leaves, and fruit even when there is some unusual exigency, such as a heavy wind or a load of snow or sleet. Furthermore, in some plants the stems serve (5) as a place of storage for surplus food and (6) as a place of storage for certain waste materials which the plant cannot get rid of otherwise. In some plants (7) the stems contain chlorophyll and therefore take some part in the work of photosynthesis, and (8) some stems serve as a means of propagation, that is, of reproduction.

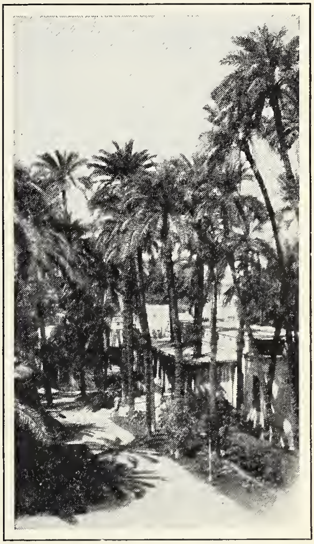

FIG. 60. The leaves of certain palms furnish effective shelter when used for roofs and walls of tropical dwellings. Can you state other uses of leaves?

Economic[1] importance of stems. Plant stems have many important uses. The stems of many evergreen and deciduous trees are used for lumber. Stems are used for fuel, especially in localities where coal is not readily available.[2] The stems, or leafstalks, of celery, asparagus, rhubarb, and many other plants are used as

[1] *Economic* (e ko nom′ik): related to money profits or losses.
[2] *Available* (a vail′a bl): able to be secured or obtained.

food. Linen is made from the fibers in the stems of flax plants. Rope is made from similar fibers in hemp and some other plants. Turpentine and resin, as well as camphor, spices, and many other important drugs, medicines, and flavors, are prepared from plant stems.

Self-test on Problem VI–B. **1.** Stems and branches grow longer by means of *buds* which develop on their *sides.*

2. The tip of a growing point of a stem is protected by modified *cortex.*

3. The branches of dicots develop from *flowers* on the branches.

4. *Monocotyledons* increase in thickness *more* rapidly than do dicotyledons.

5. *Monocotyledons* develop cambium in their *vascular* bundles as long as they live.

6. In *dicotyledons* new bark is constantly being formed from *cambium* cells.

7. The pith rays of the dicotyledon carry water *vertically* in the stem.

8. Dicots *always* have one growth ring each year.

Problem VI–C · What are Some of the Structures and Functions of Roots?

Roots and their structures. ***Experiment 21.*** How are roots adapted for securing water and dissolved minerals from the soil? Plant a few beans, peas, or corn grains in moist sawdust or sphagnum moss. After a day or so remove the sprouted seedlings[1] and examine them carefully. Can you find the primary root (the first root formed) (Fig. 61)? the secondary roots? the root hairs? Describe in a sentence or by means of a diagram any structures that you observe which might be of use in securing water and minerals. Carefully remove from the ground several plants of different kinds, such as the dandelion or plantain, taking with them a considerable quantity of the soil around the roots. Be careful to disturb the root system as little as possible. Wash the root systems free of soil and examine them carefully. Can you find the primary root and the secondary roots in each case? Record what you observe which seems to offer an answer to the question asked at the beginning of this experiment.

[1] *Seedling* (seed′ling): a very young plant that is still securing part of its food from the seed.

Experiment 22. What is the structure of a root? Soak some pea seeds and place them between moist paper towels or sprout a Wandering Jew plant (*Tradescantia*) in water. Cut off a very small root. Examine it with both the low power and the high power of the microscope. Do you find one or more vascular bundles? Can you determine whether or not the root as a whole is made up of cells, and whether or not the bundles are composed of cells? Can you find any root hairs? Describe your observations in a few sentences or by means of diagrams. Cut from a young root of Wandering Jew or other plant a thin longitudinal section. Mount it on a microscope slide and examine it as before. Can you determine whether the root is made up of cells? Is the structure near the tip like that farther from the tip? Place the root of a seedling in eosin or red ink. After a day cut cross sections and examine them to see whether you can find the tissues through which the liquid rose. Describe your observations in a few sentences or by means of diagrams.

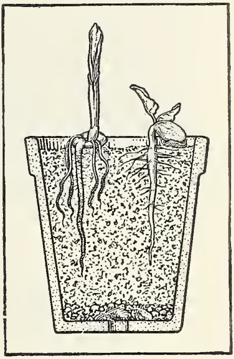

FIG. 61. Seedlings of a monocot (corn) and of a dicot (bean). In what sense does a plant pay to its offspring the debt owed to its ancestors? Compare these two seedlings

Experiment 23. What is the structure of a root hair? Mount on a microscope slide a root hair from the seedling of such a plant as bean or corn. Examine it under both the low power and the high power of the microscope. By means of a diagram show its structure.

Exercise on scientific method (criticizing procedures). Can you suggest any changes in the last two experiments or any additions which might enable you to be more certain that your observations were complete and accurate? Justify your answer.

Roots branch from the base of the stem and divide until the smallest branches of the root are somewhat like the smallest branches of the stem. Important structures of the root are (1) the epidermis, which is a thin layer of cells on the outside; (2) next to the epidermis the cortex, consisting of a number of layers of cells; (3) the vascular bundles, which continue throughout the root system from the smallest rootlets into the stem (Fig. 62, *A*). The chief function of the epidermis is to absorb moisture from the

soil; of the cortex, as is true of the cortex in the stem, to protect the delicate tissues within; and of the vascular bundles, to

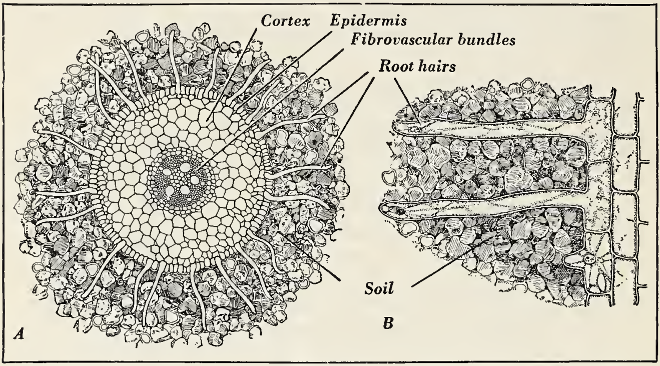

Fig. 62. Can you describe the functions of the labeled structures in these diagrams of (*A*) the cross section and (*B*) the longitudinal section of a young root?

transport soil water upward and food materials downward. The growing part of the root is near the end, just above the rootcap.

*During the growing seasons the epidermal cells of the smallest roots, or rootlets, produce elongated hairlike growths, called root hairs (Fig. 62). The root hairs have thin walls, and their protoplasm is continuous with that of the epidermal cells from which they grow. The winding root hairs come into close contact with the particles of soil and with soil moisture and thus, having thin walls, are able to absorb water and with it the dissolved minerals from the soil.

Root hairs bear an important relation to the loss of leaves by deciduous trees in the fall. As the soil becomes colder, root hairs are developed less and less abundantly, and finally the water supply of the plant is almost stopped. Reduction of the water supply is one cause of the shedding of leaves. By dropping its leaves the plant reduces the amount of transpiration, and thus adjusts itself in part to the reduced water supply from its roots.

Experiment 24. Are there definite types of root systems in different plants? Carefully remove from the ground a number of plants, such

FIG. 63. With so many roots exposed, what holds these trees upright?

as weeds of various sorts, grasses, and vegetables, with considerable amounts of soil attached. Remove the soil from around the roots by careful washing. Compare the root systems. Do any have a single main root with numerous small roots? Do any have several main roots of about equal size? Do any have no main roots but instead a large number of roots of about equal size? Are there other distinct types? Summarize the results of your observations with statements or diagrams.

Exercise on scientific method (evaluating data). Can you be sure that from your observations you have discovered *all* the different types of root systems? Explain.

Roots as anchors. Observations of exposed places, such as rocks, cliffs, and stream beds, enable one to comprehend the growth that roots must make in order to support the plants to which they belong (Fig. 63). Many plants, chiefly dicots, have one root which is large, strong, and deeply placed and which branches to form the smaller roots. This main root, which descends from the base of the stem, is called a taproot. Such a taproot is found in the hickory, walnut, pecan, some oaks, the carrot, beet, and turnip. In the last three named the taproot is also a structure for storing surplus food. In other plants, chiefly the monocots, root systems are finely divided. Such root systems, in which no taproot or main large roots exist, are called fibrous roots. Some plants, such as woodbines and ivies, in addition to their ground roots develop along their stems rootlike structures called hold-fasts, with which they cling to other plants or to rocks or walls

for support. A few of these plants are parasites. In the mistletoe, for example, the roots actually penetrate the host plant (Fig. 9, p. 19), spread in the phloëm of the host branches, and steal food material made by the host plant.

The roots of trees and grasses are of great economic importance in preventing the erosion of soil. In the Bad Lands of South Dakota, in increasing areas in other parts of our country, and in great areas of China, the land is worthless because the fertile top soil was washed or blown away after the plants on it had been destroyed.

***Summary of the functions of roots.** The most important functions of roots are (1) to support the plant; (2) to absorb soil water; (3) to conduct liquids. In certain plants, such as the turnip, beet, and other root vegetables, the roots serve (4) as the chief storehouse of the plant's surplus food materials. In still other plants — for example, the sweet potato — the roots may serve (5) for propagation.

Man cultivates many garden plants, such as beets, carrots, parsnips, and turnips, for the sake of the food energy which the plants have stored in their roots. He uses for medicine the roots of a few other plants, such as ginseng and aconite.

Self-test on Problem VI–C. **1.** The structure which the root has and which the stem does not have is *pith*.

2. Moisture is chiefly absorbed through the __(?)__ of the root.

3. Soil water and food materials are transported in the root through the __(?)__.

4. The *dicot* plant develops *more* root hairs in the fall than in the spring.

5. In general the *monocots* develop taproots.

6. One would need to dig *more* deeply to remove a monocot than a dicot of the same height.

Problem VI–D · How do Various Plants Solve the Problem of Food Storage?

Storehouses of surplus energy. If a plant's structure and activities should relate only to the individual plant's life, there would be no need for it to manufacture and store more food than

that required for its own demands. But the plant must reproduce. Therefore it produces and stores enough food to supply not only its own needs but also those of its offspring, until the young plants have grown a sufficient crop of green leaves to make their own food. Man and other organisms benefit by the food-storing of green plants, but it must be understood that the plant makes and stores no food energy except what would ordinarily be used for its own purposes and for propagation.

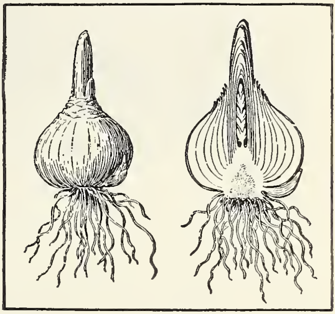

FIG. 64. How may one distinguish the underground leaves of this plant from the stem?

As has been stated, various plants store surplus food in leaves, roots, stems, or seeds. Storage of food energy is so important that it will be of interest to study further the nature and variations of the storage habits of many different plants.

Leaves as storehouses of energy. Although there are usually more or less starch and sugar in green leaves, these food substances are there as immediate products of photosynthesis and not for storage. In fact, relatively few plants store surplus food in leaves, and these usually do not store it in green leaves aboveground, but in closely folded clusters of fleshy leaves underground. The onion and other members of the lily family have such leaf clusters, or bulbs (Fig. 64).

Stems as storehouses of energy. The sugar in the sap of sugar cane is direct from the chlorophyll factory. It is not stored but is in process of being transported to all parts of the plant as food. The sweet sap of the sugar maple is food which was stored during the preceding year, and which has been changed into sugar in order that it might be moved through the tree for use in starting the season's growth. In some plants food is stored in the pith or in the cortex. More often, however, storage is in parts of underground stems, that is, stems below the surface of the ground.

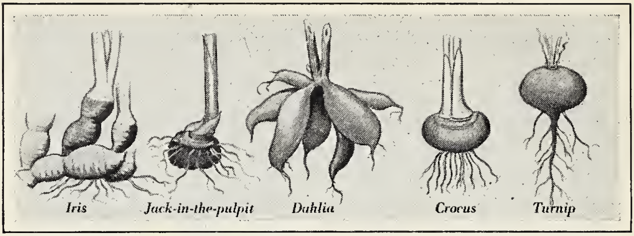

Fig. 65. What plant structures which grow aboveground and in which food is stored can you name? How can one distinguish underground stems from roots?

There are several types of underground stems. They differ from one another in form, structure, and position. Many plants, such as Solomon's seal, wild ginger, iris (Fig. 65), quack grass, Canada thistle, and some ferns, have the type of underground stem (rhizome) from which either branches or leaves with strong petioles grow into the air from different points. This type of stem may persist for many years and may serve constantly as a storage region for surplus food. The onion, the tulip, and the lily have each a small button-shaped underground stem from which the fleshy leaves grow. Such bulbs, though composed chiefly of leaves, do nevertheless have underground stems. Plants such as the gladiolus, Indian turnip, jack-in-the-pulpit, and crocus have rounded underground stems (corms) in which food is stored. The leaves are not distinct but are scalelike structures on the surface of the corms. The white potato has still another type of rounded underground stem, usually called a tuber.

Roots as storehouses. The fleshy roots of such plants as the beet, turnip, sweet potato, carrot, and parsnip must not be confused with the underground stems described in the preceding paragraph. An underground stem has the same plan of structure as have the stems that grow aboveground (Fig. 65). Roots have a somewhat different structure. Not only do roots contain surplus stores of food, but those that grow in desert regions also may store water. One such plant of southwestern United States, called the man-of-the-earth, or wild potato, has storage roots which are sometimes several feet long and a foot thick and which may weigh

as much as a man. Travelers sometimes dig up this root to secure the water stored within it.

Seeds and fruits as storehouses. Flowering plants store surplus food in their seeds. The amount of food stored in a seed may be very small, as in orchid or mustard seeds, or it may be very large, as in seeds of the bean, corn, wheat, or hickory. Additional foods, chiefly sugar and starch, are stored around the seeds or stones in such fruits as apples, pears, plums, peaches, and grapes. In such fruits these foods outside the seeds are lost to the plant when the fruit falls or is picked. It does not serve the new plant as food, because the new plant is inside the shell and does not begin to grow until after the fleshy part of the fruit is gone. Nevertheless this provision for food storage is of some value to plants in propagation. The pulp attracts birds and other animals which may carry the fruits away and, by dropping the seeds at a distance, may enable the plants to spread to new localities.

Self-test on Problem VI–D. **1.** The function of food storage by plants is to supply food (1) for the needs of the plant itself and (2) for the use of *human beings.*

2. Plants that store food in the leaves *often* store it in thickened leaves.

3. In the common white potato surplus food is stored in the *roots.*

4. Roots of some plants contain both surplus food and surplus __(?)__.

5. A young peach plant consumes *little* of the fruit around the stone.

6. Some woody plants store surplus food in the *cortex.*

Self-test on Organization of Materials Illustrating a Principle (Division of Labor). First define *division of labor*, making a complete sentence. Then make an outline similar to the following:

Division of Labor in a Green Plant

I. Roots
 A. Unique[1] functions
  1. To anchor the plant
  2.
  Etc.
 B. Functions shared with other parts
  1. To transport soil water and food materials
  Etc.
II. Stems. (Continue the outline in the same way with stems and leaves)

[1] *Unique* (u neek′): peculiar to the thing itself; not shared with any other.

Self-test on Organization of Facts. Compare the characteristics of monocots and dicots (see "Suggestions for Effective Study," p. xvi). Add to the points given as samples all the points of comparison you can.

MONOCOTYLEDONS *compared with*	DICOTYLEDONS
Stems	Stems
Similarities	Similarities
1. Support leaves	1. Support leaves
2. Vascular bundles have xylem and phloëm	2. Vascular bundles have xylem and phloëm
3. Etc.	3. Etc.
Differences	Differences
1. Stem largely pith	1. Stem mostly wood
2. Etc.	2. Etc.
Leaves	Leaves
Etc.	Etc.

When you have completed this organization, write a statement of a few sentences summarizing the important similarities and differences.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Why does cutting a ring completely around the stem through the bark of a dicot tree kill the tree, while a similar cut around the stem of a monocot plant does not necessarily kill it?

2. Against what kinds of enemies does thick bark protect a plant? (See page 24, Chap. II, list of kinds of enemies.)

3. How many economic uses of stems can you list?

4. What disadvantage would plants suffer if all of them were to store surplus food in their green leaves?

5. Why is it so difficult to cut through the dry stem of a corn plant? Why is such a stem stronger than it would be if all the hard outer cortex were compressed into a solid cylinder?

6. Warm and sunshiny winter days followed by very cold weather may result in killing evergreens. Explain.

7. Aquatic plants do not usually possess root hairs. Explain.

8. Why are young vegetables sweeter than old ones?

9. Suppose a certain tree, which is fifteen feet tall, grows in height at the rate of two inches a year. When the tree is ten years old a nail is driven into the trunk three feet from the ground. How far from the ground will the nail be when the tree is twenty years old?

10. How do annuals and biennials differ from perennials? (See Glossary.)

Exercise on Scientific Method. 1. Observation and Comparison. Study Figs. 64 and 65 to determine the differences between types of underground stems. List differences you can determine; then check the accuracy of your observations and comparisons by consulting an advanced biology text or an encyclopedia.

2. Making Inferences. If a tree is girdled late in the summer, it usually will not die at once. It will even put forth leaves the following spring and live all through that growing season. But it will die before the second spring. What facts have you learned in this chapter that explain these observations?

Project 3. To make a collection showing some differences in buds and branches. In some plants, such as lilac and sumac, the terminal buds of one year do not start the growth of the next year. This produces an irregular appearance in the younger branches. In other plants, such as maple and ash, the terminal bud produces great growth in length, and the lateral buds produce branches in opposite pairs. In most plants an injury to one or several buds often results in the growth in length being taken up by other buds which under usual conditions would not have grown in such a way. Collect and mount on a large piece of cardboard several illustrations like the one given above and write a description of each one.

Special Reports. 1. How do "air plants," such as certain tropical orchids, secure water? (Look up "epiphytes" and "orchid" in an advanced botany textbook or an encyclopedia.)

2. Why are plants such as quack grass hard to get rid of?

3. What are hydrophytes and xerophytes?

Question for Debate: *Resolved,* That dicotyledonous plants have proved of more benefit to man than monocotyledonous plants.

Chapter VII · Competing for Light Energy

Questions this Chapter Answers

What ways have leaves of securing the sun's energy?
How are plants adapted to varying amounts of sunlight?
How does competition for radiant energy affect the forms of plants?
How are the habits and structures of the early flowering plants in dense forests adjusted to their life under the trees?
How do trees adjust themselves to varying amounts of sunlight?

Problem VII–A · How are Various Kinds of Plants Equipped to Compete for the Sun's Energy?

Many types of leaf arrangement. When we consider that all green leaves are factories to transform the sun's energy into food, it may seem strange that there are so many different types of leaf arrangement. Almost any plant-covered area presents many types. A study soon discloses the fact that the form or position of almost every leaf is in some way related to the leaf's exposure to proper lighting. Indeed, leaves that are not well lighted do not perform their functions properly. Therefore plants suffer for lack of sufficient supplies of energy if too many of their leaves are constantly shaded. The best arrangement exists when on each plant, no matter what form of leaf it has, the leaves are so arranged that each one receives some sunlight for a good part of each day. Few plants have leaves that are all well lighted all day, but every plant has a leaf arrangement which permits it to secure as much as possible of the available sunlight. We cannot expect an ideal or perfect arrangement to be found often, since there are many difficulties to be overcome by the plants in exposing their leaf surfaces to the sunshine.

*Typical leaf arrangements are illustrated by familiar plants. The leaves of the horse-chestnut are in pairs, with one leaf on each side of the stem and with each pair at right angles to the pair immediately above or below (Fig. 66). The leaves of the

apple have a spiral arrangement (Fig. 66). The leaves of such plants as the banana, caladium, and palm are relatively large and few in number. The petioles are sufficiently long and heavy to raise the expanded leaf surfaces high enough to insure good lighting. The petioles and leaves of climbing plants that grow upon rocks, fences, or walls twist about so as to present a broad surface to the light (Fig. 67, *B*). The leaves of such plants as dandelion, plantain, and dock, which grow close to the soil, are arranged in a rosette pattern (Fig. 67, *A*). In these plants the petioles of the upper leaves are shorter and more nearly upright than are those of the lower leaves. They are so arranged on the stem of the plant that the upper leaves fit into the spaces between the lower ones.

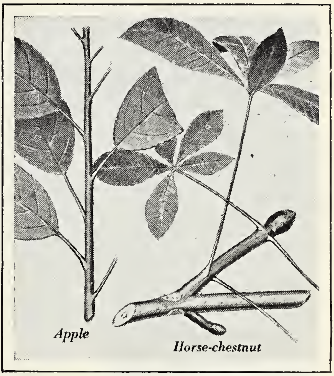

Fig. 66. What advantages do plants derive from having these leaf arrangements?

Fig. 67. *A*, dock; *B*, squash. Compare the leaf arrangements of the dock and the squash with that of the mullein (Fig. 68). (See "Suggestions for Effective Study," p. xvi)

Rosette plants are often biennial; that is, they require two years to complete their life cycle. They do much photosynthetic work the first year and store surplus food in the underground

stems or roots. The next year they send up stems on which flowers develop and produce seeds (Fig. 68). These stems bear leaves which in form seem to be quite different from those that compose the rosette. A close inspection, however, shows that the arrangement of the leaves on the stem is practically unchanged from that in the rosette. The long stem now serves to separate the leaves. The rosette arrangement keeps the leaves close to the earth, and thus reduces the danger from excessive drying by winds and helps to avoid rapid changes in temperature. Rosette plants usually do chlorophyll work later in the autumn and earlier in the spring than do most other plants.

Fig. 68. Compare the relative advantages of the rosette arrangement (Fig. 67, *A*) with that of this mullein plant

Adaptations to varying amounts of sunlight. The intensity of sunlight at midday is much greater than in early morning or late afternoon. It is much greater in summer than in early spring. It is also much greater at the top of a forest or in an open meadow than under the forest trees. An exposed rock or sandy surface is much more intensely lighted than is a shaded cliff or a deep ravine. Yet plants in all these regions are at work, securing and using the sun's energy. How can plants work under such a wide range of conditions?

In early springtime, before the forest trees have developed their leaves, the forest floor may have a display of early flowers of many kinds. Trillium (or wake-robin), spring beauty, bloodroot, anemone (or windflower), hepatica, violet, buttercup, and many others appear in flower soon after the snow is gone (Fig. 69). Some of these produce flowers before their leaves appear. Such plants have clear green leaves which are usually thin and delicate. They thrive and grow rapidly in the milder light of early spring. Seeds ripen in a few days or at most in a few weeks. By the time the forest trees have completed their year's crop of leaves, and

when the more intense summer sunlight has come, these early spring plants have manufactured abundant supplies of food and have stored the excess in their underground stems or roots. The leaves usually die at this time, and we do not see these plants again until the next spring. Then the stored food of the preceding year provides the necessary energy for the early spring flowers and for making the new crop of leaves. The leaves of a few spring flowering plants, as the hepatica, do not die in midsummer, but become inactive and persist through the summer. Most of their work was accomplished in the early springtime. All these plants avoid excessive lighting of midsummer or excessive shading of the heavy forest by practically finishing their year's work in the early spring sunlight. The habit of storing food is an important part of the seasonal adjustment to the lighting problem.

Fig. 69. When do plants such as these hepaticas do their food-making?

Many other plants, such as ferns and trilliums, are able to live under the shade of forest trees throughout the summer. They usually have broad and thin leaves. The seedlings of forest trees themselves may start to grow under the milder light of the dense forest, and may secure enough sunlight to permit them to live until they are several years old. In fact, the seedlings of many kinds of forest trees cannot get started except under the protection of the shade of the dense forest. This same shade, however, prevents the continued growth of the seedlings into mature trees. It is only when an opening is made by the removal of the older trees that the seedlings can secure enough light to permit them to become large trees.

Some plants which grow in direct exposure to intense summer lighting have the edges of their leaves turned toward the sunshine, thus reducing the intensity of light upon the leaf surfaces.

Reaching for light. ***Experiment 25.*** Do plant stems tend to grow toward or away from light? Select two small potted plants of the same kind and as nearly alike as possible. Secure two large boxes of the same kind, such as shoe boxes. Cut two windows of the same size in opposite sides of the two boxes. Place one plant in each box and place both of the boxes in equal lighting in a window (Fig. 70). Keep the boxes closed except when watering the plants. Do not change the positions of the plants. After a week or so the plants should indicate the answer to the question at the beginning of this experiment. What is the answer? State it in a complete sentence.

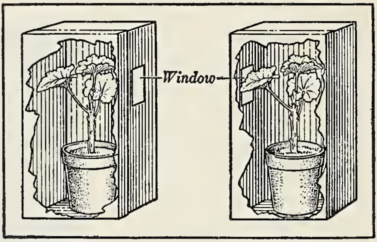

FIG. 70. What was the value of the check experiment following Experiment 25?

Check experiment. After the two plants have grown sufficiently so that there is no doubt concerning the answer at the beginning of Experiment 25, turn both plants halfway round. Continue the experiment as before. Is the result of this experiment the same as or different from that of Experiment 25?

Exercise on scientific method (using controls and isolating the experimental factor). Why were two plants used instead of one in this experiment? Each served as a control for the other. Explain. How many factors were identical with both boxes? Which was different? This was the experimental factor.

The forest-tree seedlings described in the last section sometimes grow in such numbers that they are densely crowded. The amount of light energy available is not enough to permit many to continue to live. In fact, all the seedlings may finally die unless an open space is made by the removal of older trees.

Young trees may endure severe shading for many years, may become twenty to thirty feet tall, and not more than an inch or two in diameter. They bear leaves only at their tops or at the outer ends of their slender branches because there is severe competition not only among the trees but among the leaves and buds on the same branch. They have barely enough leaves to permit them to live, but not enough to allow them to prosper. Their stems

are so slender that sometimes they would not support the weight of leaves and branches if they stood in the open where strong winds could strike them. The form of such plants has resulted from their effort to secure sunlight in locations where the struggle to live is very severe. A maple tree which was attempting to grow under such forest shade was found to be twenty feet and four inches tall. It had leaves on its upper three feet only. When cut, the stem near the ground was found to be one and a quarter inches in diameter. It had thirty-one growth rings.

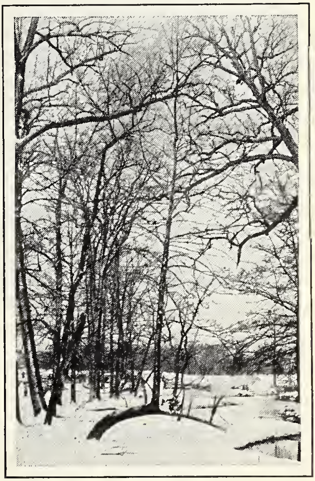

FIG. 71. Explain how this limb developed into the upright part of the tree

Trees that have grown in open fields have forms that differ from those of other trees of the same kind that have grown in more crowded conditions. As a result of the severe struggle for light the latter prune themselves. Their lower limbs, which become shaded, die and finally fall off, thus leaving a tall, straight, and well-pruned stem.

Trees that have been injured often show remarkable ability to adjust themselves to the sunlight. One or more of the limbs of a fallen tree the roots of which remain in the soil may assume the shape of a tree (Fig. 71) and expose their leaves to light as the whole tree did before.

The stems of some plants which root in the ground climb upon the stems of others or upon houses, fences, or any other available support. By such means these climbers, or vines, can raise their leaves to the light by the use of support that is not their own. Some climbers, such as grapes and cat brier, develop special structures called tendrils, which twine closely about the support and provide a firm attachment. Others, such as the morning-glory, bittersweet, and trumpet creeper, wind their stems about

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FIG. 72. *A*, a wall of ivy; *B*, (left) Virginia creeper and (right) poison ivy. How do these climbing plants secure light energy?

their support (Fig. 72). Such winding stems sometimes become so tight and persist so long that young trees around which they twine may even grow over and inclose them or may be killed by them.

Experiment 26. What part of a growing plant stem is most sensitive to light; that is, does the older or the newer part of a plant stem grow toward the light? Arrange two plants in shoe boxes, as in Fig. 73. When their stems have bent in opposite directions toward the light, turn them so that the stem of each plant is turned away from the window in its box. Tie a small paper bag over the top of one plant to shut off the light; a bag made of black photographic paper will be more certain to exclude the light (Fig. 73). Observe the two plants after a few days. Does either stem or both stems now bend toward the light? When you are certain about your answer to this question, transfer the bag to the end of the stem of the other plant. After a few days observe again.

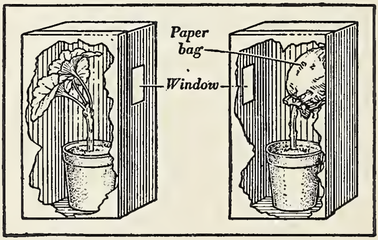

FIG. 73. Are old or young stems more sensitive to light?

Answer with a complete sentence the question at the beginning of this experiment.

Exercise on scientific method (using controls and isolating the experimental factor). Why were two similar plants used in this experiment? Which conditions were the same with both plants? Which condition was different? This was the experimental factor. Each plant was a control for the other. Explain. What was the purpose of transferring the paper bag from one plant to the other after the results of the first part of the experiment were clear? In what sense was the second part of the experiment a control experiment for the first part?

Self-test on Problem VII–A. 1. In order to survive, *every* green *plant* must have its leaves so arranged that they are sufficiently exposed to the sunlight.

2. In general rosette plants carry on the process of photosynthesis for a *smaller* part of the year than do other plants.

3. Most of the delicate flowering plants carry on the process of photosynthesis for a *greater* part of the year than do other plants.

4. *No* kinds of forest trees require shade in order to begin growing.

5. If a green plant has too *few* leaves, it will starve to death.

6. A branch with too *few leaves* may die.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. What survival values are found in the rosette leaf plant which enable certain plants possessing it to live in exposed rocky and sandy soil where most other plants cannot survive?

2. Is a plant which uses the body of another plant in order to gain light a parasite, a saprophyte, or an epiphyte? (See Glossary.)

3. Why do plants which live in the shade of forest trees usually have broad and thin leaves?

Project 4. To secure examples of various arrangements of leaves. Find, in the woods, fields, garden, or greenhouse, plants the leaf arrangements of which illustrate the types described in this chapter. Photograph, diagram, or describe each of these so as to show its arrangement. Can you find any plants of which the leaf arrangements seem distinctly different from those described in this chapter?

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GANONG, W. F. A Textbook of Botany for Colleges. The Macmillan Company, New York.

HOLMAN, R. M., and ROBBINS, W. W. General Botany. John Wiley & Sons, Inc., New York.

UNIT III · *The Living Things which Compete for Energy*

PROBLEMS DISCUSSED IN THIS UNIT

It would be interesting indeed if one might see all the plants and animals now living on the earth. There would be more than a million different kinds. At one end of the scale of size would be the sequoia trees and the whales. At the other end would be the plants and animals too small to be seen with the most powerful miscroscope yet invented. Only relatively few of the forms would be known by any one person. Now suppose one had the gigantic task of naming and classifying all these living things. Could it be done? The task would seem hopeless of accomplishment. Yet scientists have already classified and named several hundred thousand species of living things.

This unit tells how biologists classify animals and plants. But more important than the classification, it tells how the various groups are fitted to survive in the struggle for energy. The major problems discussed are these:

How are living things classified?

What are important characteristics which aid the various great groups of plants and animals in survival?

How do these groups, from the lowest organisms to the highest, illustrate increasing complexity of structure and function?

Of what importance are these groups to man in his struggle for energy?

Chapter VIII · How Living Things are Grouped and Named

Questions this Chapter Answers

Why is a scientific classification of plants and animals necessary?

How is a scientific classification of living things built up?

How are plants and animals given scientific names?

How do biologists use the system of classification?

Problem VIII–A · How are Living Things Classified?

Naming animals. Imagine yourself on an island where none of the animals and plants is known to you (Fig. 74). You would soon observe that some animals live in the water, some on land, and some in the air. It would be correct to group them as land animals, water animals, and air animals if you needed to consider only their habitats. You would soon observe, however, that some of the animals in each habitat might move into one or both of the others. Then you would need to change their classifications. It would be a poor classification that required a change of grouping whenever an animal moved from one region into another. You would need to find some other basis of classifying the animals on your island. You might observe great differences between the animals in each of these regions. Thus some of those in the water would have fins and no legs, some would have shells and no fins, and some would have no fins, legs, or shells, but would crawl on the mud at the bottom of the water. To say that they were water animals would not give much information about them, except that they might be found in the water.

A more satisfactory way to classify animals would be to make a group of those that have similar body structures. On your island you might place in one group all that were covered with scales and that used fins for locomotion; in another group, all that had fur and four legs; and in another group, all that had feet and feathers and that flew in the air. In this way you could group

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FIG. 74. If you should discover such creatures as these (lizards of Galapagos Islands), how would you determine what kind of animals they are? A trained scientist, by examining their structures, would be able to classify them

together all animals that seemed related in their structures. The modern plan of classification is based on this principle, as we shall see in our further studies.

You would probably give names of some sort to the animals you might observe on the island. You might call one "that little animal that runs very fast, with gray fur and a long tail." But if you were to talk about this animal, you would find that a shorter name would be much more convenient. Your experiences would be the same as those of scientists in finding a way of naming plants and animals for scientific study. The first names given were long and consisted of many descriptive terms.

Possibly you would decide to use a shorter descriptive name for the animal, as "long-tailed mouse." This name might serve well enough until it was discovered that people on the neighboring island used exactly the same name for an entirely different animal. Common and local names for animals and plants have indeed come to mean such different things in different places that scientists do not depend on them. Gopher in one part of the United States is a small furry animal with pouched cheeks. In another part it is a land tortoise. In still another part it is a snake. The goldfinch is also called the wild canary, the thistle bird, and the golden warbler. The word meaning "dog" is *chien* in France,

Hund in Germany, *perro* in Spain, and *go* in certain parts of China. Common names are desirable only when it can be certain that they will be understood.

*We must have names which students in all parts of the world can recognize as belonging only to certain kinds of plants and animals. The necessity for such a scheme for naming was felt long ago. Many plans for classifying and naming plants and animals have been suggested. The names now used serve as a scientific language among all nations in much the same way that chemical symbols do. Scientific classification has been built up through careful study of the likenesses and differences in the structures of animals and plants.

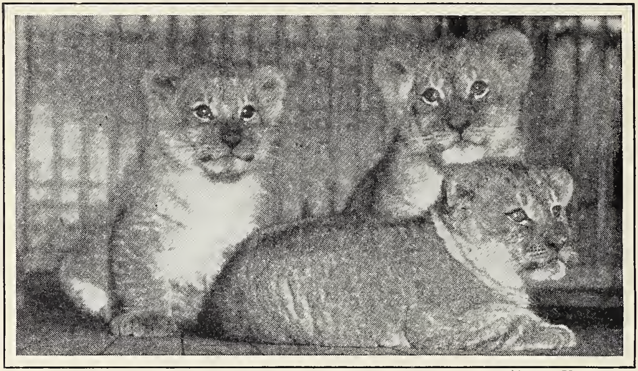
How the plan of classification was made. There are many different breeds of dogs, such as collies, Saint Bernards, greyhounds, poodles, and terriers. But, different as they are, they are all dogs, and one readily recognizes them as such. They are all of the same species, that is, all are of the same special kind of animals. A *species* is therefore defined as a group of closely similar individuals.

Dogs are domesticated[1] forms of related animals, such as the wolves, coyotes, and jackals. Dogs, wolves, coyotes, and jackals all belong to the same genus. A *genus*[2] is defined as a group of related species (Fig. 75). It is easy to see the generic[2] resemblances of dogs, wolves, coyotes, and jackals. This is not always easy in some other genera.[2]

Every animal or plant has a scientific name of two parts. The first, which begins with a capital letter, indicates the genus, and the second, usually beginning with a small letter, indicates the species. Scientists have agreed that the genus and species names should always be in Latin. This agreement was made because at the time this system of names was adopted Latin was the common language of scholarly people. Thus any dog is known to scientists as *Canis familiaris*; any wolf, as *Canis lupus*; any coyote, as *Canis latrans*; and any jackal, as *Canis aureus*. *Canis*, then, is the genus name, and *familiaris, lupus, latrans,* and *aureus* are the

[1] *Domesticate* (do mes'ti kate): to tame or train for domestic use.

[2] *Genus* (je'nus): a group of related species; plural *genera* (jen'e ra). *Generic* (je ner'ik): pertaining to a genus.



Newton H. Hartman

Fig. 75. Two-months-old lion cubs of the Philadelphia zoo. Can you name any other animals to which you think the lion is probably related?

species names. This very simple way of naming plants and animals by two (and sometimes by three) names was invented by a Swedish botanist, Carl Linnæus, and was perfected by him about 1750; it came into general use in the decade that followed.

Making larger groups. In building the system of classification, a number of similar genera are put together in one *family*. For example, all the various kinds of genera of doglike animals are grouped into one family, the Canidæ. Similarly all the various genera of catlike animals, such as the house cat, the lion, the tiger, and the leopard, belong to the family Felidæ. The next step in the system of classification is to find characteristics of structure which a number of families hold in common. It is easy to see that dogs, cats, and bears have some characteristics in common. One such characteristic is the structure of the teeth and jaws, which has to do with methods of securing food to supply energy. Therefore all the flesh-eaters that have such teeth and jaws are placed in one group. In another group are those animals, such as rats and mice, that have teeth and jaws fitted for gnawing their food.

Groups made up of a number of families are called *orders* (Fig. 76). Thus the dog family, the cat family, the weasel family,

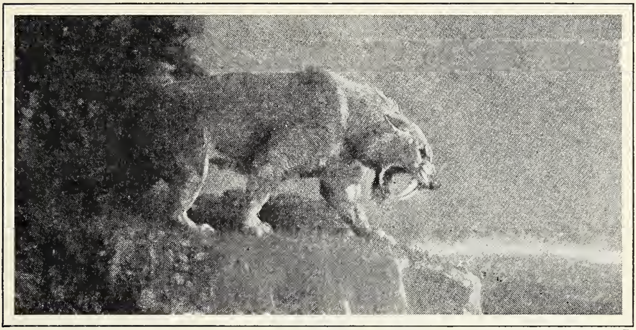


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Fig. 76. The saber-toothed tiger lived thousands of years ago in various parts of North America. Judging from its teeth, in which order of mammals would you place it?

and other animals of prey together make up the order Carnivora. The squirrel family, the rat family, the rabbit family, and other families which comprise gnawing animals make up the order Rodentia.

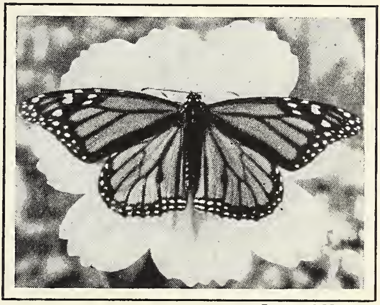
The next step in the system of classification brings together different orders. A dog is not much like an elephant or a horse; yet it is more like these animals than it is like a chicken or a snake. One characteristic which dogs, cats, horses, and elephants have in common is a special structure with which to feed milk to their young. Therefore all orders of animals having this character are grouped together. Such a group is called a *class*. Ten or more orders make up the class called Mammalia. Other classes are the Aves, which includes the animals with feathers, the birds; the Reptilia, which includes the snakes, lizards, crocodiles, and others; the Pisces, which includes the fish; and there are other classes that need not now be listed.

Dogs, fish, birds, and snakes are not much alike; yet they are more nearly alike than they are like insects, worms, or starfish. All the Mammalia, Pisces, and Reptilia have spinal cords, while snails, sponges, worms, and insects do not. Hence all the classes of animals having spinal cords are grouped together and are called Chordata. Such a large grouping together of many classes is

Kingdom . . .	Animal	Animal	Animal	Animal	Animal	Animal	Plant
Phylum . . .	Chordata	Chordata	Chordata	Chordata	Chordata	Arthropoda	Spermatophyta
Class	Mammalia	Mammalia	Mammalia	Mammalia	Aves	Insecta	Dicotyledoneæ
Order	Carnivora	Carnivora	Carnivora	Primates	Passeres	Orthoptera	Campanulales
Family	Canidæ	Canidæ	Felidæ	Hominidæ	Turdidæ	Locustidæ	Compositæ
Genus	Canis	Canis	Felis	Homo	Planesticus	Melanoplus	Taraxacum
Species	familiaris	lupus	domesticus	sapiens	migratorius	femur-rubrum	officinale

Fig. 77. How living things are classified. On this chart the differences between the dog and the wolf do not appear until the species is reached. At what point should you expect the classification of a fox and of a fish to differ from that of the classification of the animals named here? Does the fir tree or the lily belong in any of the groups in this chart? Explain

called a *phylum* (plural *phyla*). The final step in constructing the scheme of classification consists in grouping the phyla into two great kingdoms of living things, — the animal kingdom and the plant kingdom. In the animal kingdom ten phyla[1] are usually recognized; in the plant kingdom, four.



Lynwood M. Chace

FIG. 78. Monarch butterfly (*Danaus archippus*) on cosmos (*Cosmos pinnatus*). The common name may be either like or very different from the scientific name. Should you expect the moth to belong to the same species, genus, family, order, class, and phylum as the butterfly? Justify your answer

*** Summary of the plan.** Every animal and plant can be classified according to the plan as outlined. The various groups in this scheme of classification have been built up through a study of the differences and likenesses in the structure of plants and animals, so that the scheme shows the relationship of one group to another with respect to structure.

To illustrate the complete scheme of classification a chart has been prepared (Fig. 77) to show the classification of the dog, the wolf, the cat, man, the robin, the red-legged grasshopper, and the common dandelion.

In common use, only the names of the genus and species of an organism are given. Such a name as *Felis domesticus*, the cat, or as *Lilium canadense*, the Canadian lily, means a particular kind of animal or plant and will not be confused with any other. We cannot make much use of these scientific names in our ordinary conversation, but the biologist could not carry on his work effectively without such accurate names for the living things of which he speaks (Fig. 78).

[1] Biologists are generally agreed upon the ten phyla discussed in this book. But these ten phyla do not include all animals, though they include the most important ones. Biologists are not generally agreed upon the classification of animals not included in these ten phyla.

How biologists use the system of classification. Suppose a biologist were to find an insect not known to him. From his general studies he would know at once that the organism belonged to the phylum Arthropoda and to the class Insecta. At that point his positive knowledge might end. There are more than four hundred thousand known species of insects. How could the biologist find out to which genus and species his specimen belongs? First he would collect a large number of specimens of the insect. Then he would make a careful study of its characteristics, such as those of its structure, its food, its habits. When entirely certain of the facts from careful study of many specimens, he would be ready to use his insect "key." A key is a book in which the characteristics of each phylum, class, order, family, genus, and species, so far as they are known, are described completely and accurately. Keys have been prepared by biologists for all classes of organisms. When in the preceding sections we discussed the way in which a system of classification has been built up, we began with the species and ended with the phylum; in keys, however, this procedure is reversed. Thus the scientist would begin with the phylum and end with the species. By comparing the characteristics which he has discovered as belonging to the unknown insect with the characteristics described in his key, he would be able to trace the insect through the key. He would first find the order to which it belongs, next the family, then the genus, and at last the species.

If after careful comparison with the key the biologist should find that his specimens are unlike all the species described, he might conclude that his specimens are of a species of insect that is not listed in the key. That is, his specimens may be of an insect not yet known to science. He might announce his discovery to the scientific world. Immediately other biologists would attempt to secure specimens of the new insect. Each would classify it himself in order to make sure that the first biologist's classification was accurate. If they all reached the same conclusion, they would approve the announcement of the insect as representing a new species. The discoverer would add to the genus name, which we assume was already known, a new species name to designate the species he had discovered. This name might be a Latin form of the

name of the discoverer, as a mark of especial honor, as *jonesi* (discovered by Jones); or it might be a Latin form of the name of the locality in which the new species was found, as *canadensis* (found in Canada); or it might be a descriptive word, as *alba* (white). The name of the new insect would then be added in its proper place in the insect keys for future use.

Self-test on Problem VIII–A. **1.** All living things are classified on the basis of likenesses and differences in their *habits.*

2. The scientific name of any organism consists nearly always of *three Greek* names.

3. Name in order of smallest to largest these groups: class, order, phylum, species, genus, family.

4. The scientific name of an organism indicates the *phylum* and the *order.*

ADDITIONAL EXERCISES AND ACTIVITIES

Problem. Make a table similar to Fig. 77, classifying such organisms as horse, lion, or any others. Dictionaries and encyclopedias will give much information. But you will sometimes have to leave blank such items as family and order, which are difficult to find.

Exercise on Scientific Method (Using Controls). Why would it be necessary for the scientist to secure a number of specimens as the basis for classifying his insect?

Exercise on Scientific Attitudes. Which of the scientific attitudes given on pages 12 and 13 are illustrated in this description of how a biologist classifies a strange specimen?

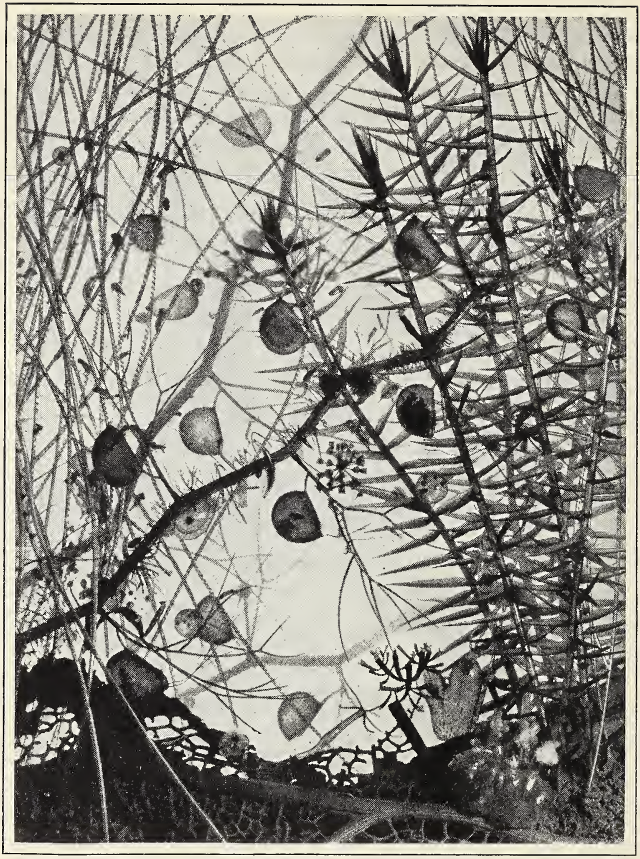


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Fig. 79. A pond jungle. This figure represents the plant and animal life in a small fraction of an inch of a pond. The objects, many of them algæ, are magnified one hundred times. In what sense are these plants engaged in the struggle for energy? The cap-shaped bodies are the traps of carnivorous, or flesh-eating, plants which capture tiny swimming animals. Many simple algæ are seen attached to the large plant stems

Chapter IX · The Four Great Groups of Plants[1]

Questions this Chapter Answers

What are the four plant phyla?
What are some characteristics of algæ, bacteria, yeasts, molds, and mushrooms?
What are some characteristics of the mosses and their relatives?
What are some characteristics of the ferns and their relatives?
How do the two great groups of seed-bearing plants differ?
What are the important structures of a flower?
What are some distinguishing characteristics of the two great groups of flowering plants?
What are important functions of the structures found in these various plants?
Of what importance to man and to other organisms are these groups?

Problem IX–A · What are Some Adaptations of the Simplest Plants (Phylum Thallophyta) which Enable them to Compete successfully for Energy?

* **There are four plant phyla.** In almost any woodland one may find examples of all the four great divisions, or phyla, of the plant kingdom. The first group includes the algæ and the fungi, such as bacteria, yeasts, molds, mushrooms, rusts, and smuts. These plants are very simple in structure and are mostly small. The second phylum includes a great variety of liverworts, and of mosses, which sometimes form a soft carpet on the hillsides or about the roots of trees. The third phylum is made up of the ferns and their relatives. In this group are some of the most beautiful of all the plants, even though none have flowers. The fourth and last phylum includes all the flowering plants, such as the wild flowers, the grasses, and the trees. We are probably familiar with more members of this phylum than of the others because these are generally the largest and most conspicuous plants.

[1] To the Teacher. In presenting a general description of the leading groups of plants and animals, it has proved effective to include only those general aspects that are necessary in gaining a clear idea of each group. More detailed discussions of life processes will be found in later chapters.

***The simplest plants.** The simplest plants (phylum Thallophyta) do not possess roots, stems, or leaves. Some of them, called algæ, are green and so can make their own food. Others lack chlorophyll, and therefore must live as either parasites or saprophytes. These are the fungi, such as the mushrooms, yeasts, molds, and bacteria. The plants belonging to this phylum vary in size from microscopic bacteria to certain sea algæ (kelps) that are of greater length than the height of the tallest tree.

Algæ. Algæ are commonly found in ponds and streams or in moist places on trees or rocks (Fig. 79). Other forms grow in the oceans. Some of the algæ consist of single cells or masses of cells. Others are made up of groups of cells arranged in long ribbonlike filaments which may extend many feet. The fresh-water forms are green or blue-green in color, while many of the salt-water forms contain so much brown or red coloring matter that their green chlorophyll does not show.

*In shaded moist places on the sides of trees, buildings, and rocks one may see patches that look like green paint. These patches are made up of algæ of a very simple kind (*Pleurococcus*). Each plant is a single cell and is independent of its neighbors (Fig. 80). It makes its own food by photosynthesis and carries on the essential life processes. In spite of its small size this alga is a very successful plant; for it is found in all parts of the world, even in the frozen wastes of the polar regions.

Experiment 27. What is the appearance under the microscope of a very simple alga (*Pleurococcus*)? Scrape off some of the green material found on the north side of a tree or similar spot. Mount it in water and examine it under the micoscope. Each of the small rounded cells you see is a single plant. Are some of the cells grouped in colonies of two or more? Draw a sketch to show the general shape and appearance of any cells or groups which are conspicuously different from those in Fig. 80.

Probably more familiar to us are the algæ commonly known as pond scums. These grow as tangled masses of green threads (Fig. 79), sometimes attached to other plants, rocks, or sticks, and sometimes floating on the surface of ponds or lakes and along the banks of streams.

Experiment 28. What is the appearance under the microscope of some of the threadlike algæ? Collect some pond scum from a pond or quiet

stream. From a study of the color, place and manner of growth, and texture do you judge that you have found more than one kind?

Fig. 80. Can you use the phrase "struggle for energy" in explaining why *Pleurococcus* is a successful plant?

Examine your specimens under the microscope. Note the long cells placed end to end to form the filament. What is the arrangement of the chlorophyll bodies? (The arrangement is different in each kind of alga.) Probably you have collected some *Spirogyra*, in which the chlorophyll is found in a spiral[1] band. Are all the cells in each filament alike? Sketch or briefly describe such differences as you find.

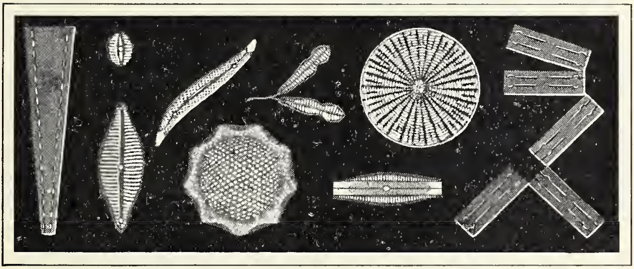


Fig. 81. Algæ with outside skeletons. Find one of these diatoms in Fig. 79

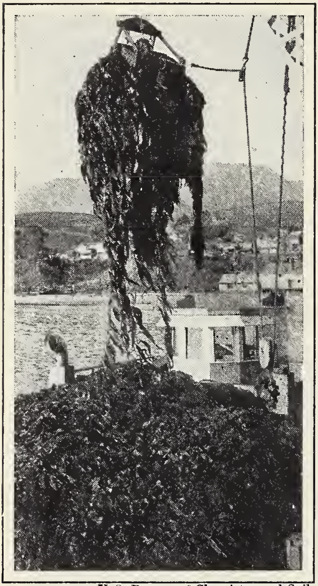
Every filament is made up of a single line of cylindrical[2] cells which are attached to one another at their ends. Since the cells are quite independent, the filament may be broken apart without injury to the cells.

One-celled plants do not, as a rule, have any sort of skeleton, though the thickened protoplasm of the cell wall of most species maintains a fixed shape. Certain single-celled algæ (diatoms) do, however, have a hard (siliceous) protective covering, secreted by the cell membrane (Fig. 81).

[1] *Spiral* (spi'ral): shaped like a corkscrew or a circular staircase.

[2] *Cylindrical* (si lin'dri kal): shaped like a barrel or like a water tumbler.

Importance of the algæ. Microscopic algæ in countless numbers are found on the ocean surface and as far below the surface as the sunlight can enter. A single quart of sea water has been found to contain more than six million of these algæ. These plants serve directly and indirectly as food for all animal life in the sea; for they are eaten by microscopic animals and these in turn by fish, which in turn become the food of still larger creatures. The ocean algæ (Fig. 82), together with the fresh-water forms, not only furnish food for aquatic animals, but also by the process of photosynthesis give off oxygen to replace that used by animals in breathing. Certain of the seaweeds are prized by man as food both for their flavor and for the iodine and valuable minerals which they contain. Agar-agar, a substance obtained from a sea alga, finds wide use as a culture medium on which to grow bacteria in the laboratory, and also as a jelly and as a remedy for constipation. At times the algæ which grow in city reservoirs may give a disagreeable fishy taste to the water.



U. S. Bureau of Chemistry and Soils

FIG. 82. These algæ (seaweed) are an important source of fertilizer. How many uses of algæ can you state?

***Fungi.** As has been previously stated the fungi include such nonflowering plants as bacteria, yeasts, molds, mushrooms, rusts, rots, blights, and smuts. In spite of the small size of most of them, the plants in this group are of great importance.

Bacteria. ***Experiment 29.*** What is the appearance of bacteria? **1.** Make a microscope slide by putting a drop of fresh sauerkraut juice on a slide and covering it with a cover glass. Examine the drop under the

high-power objective of a compound microscope. Do you see any rod-shaped bacteria? These are unusually large specimens and either are entirely harmless or are beneficial. Describe your observations either by a few sentences or by sketches.

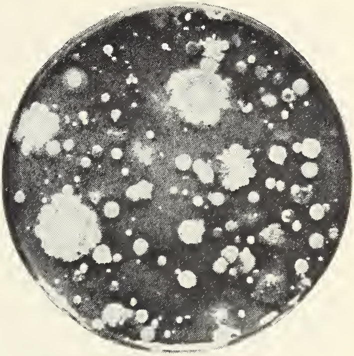


Fig. 83. Probably not all these colonies are bacteria. Can you suggest what some of the others may be?

2. Prepare a culture medium; that is, prepare material which bacteria can use as food and hence on which they will grow readily. To 200 cubic centimeters of water add 3 grams of agar-agar and 1 gram of beef extract. Boil the mixture until the agar-agar is dissolved. Strain through cotton into a flask. Sterilize again and, if the mixture is not entirely clear, strain again. Pour into sterilized test tubes or Petri dishes (Fig. 83) and let stand until cool. Set one dish aside unopened as a control. Expose other dishes or tubes (1) to the air of the room for three minutes; (2) to the air out of doors; (3) to dirt from the floor or table; (4) to contact with a dirty finger; (5) to a drop of water; (6) to a drop of milk; (7) to contact with the end of a toothpick which has been used in removing tartar from the teeth; (8) to as many other places where bacteria may be found as you like. Cover the dishes and set them in a warm dark place for several days. Why put all the dishes in the same place? Examine from day to day. How soon do the first spots, or colonies of bacteria, appear? Are they all of the same color? Make a sketch of one or more plates similar to that in Fig. 83, showing the shape and size of the bacterial colonies.

Exercise on scientific method (using controls). Explain how the unopened dish serves as a control and why a control is necessary.

*Bacteria are the smallest known plants. None of them can be seen without a microscope (Fig. 84), and it is believed that there are many too small to be seen with any microscope yet invented. Of the smallest that can be seen, it would take about twenty-five thousand end to end to make a line an inch long. Bacteria are found almost everywhere. They are so small that

they can float in the air with particles of dust. Most water contains great numbers of them. The upper layers of moist soil also are rich in bacterial life. Many of these bacteria are feeding on the bodies of dead animals, on leaves or decaying plant roots, or on plant and animal wastes. Bacteria of one kind or another will grow and reproduce rapidly wherever there are food material, moisture, and neither too high nor too low temperature.

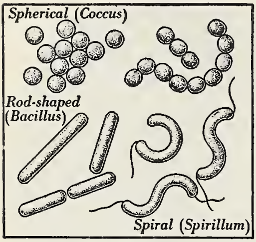


FIG. 84. The three types of bacteria. Which do you believe to be smaller, molecules (p. 62) or bacteria? Justify your answer

*As a rule bacteria thrive best in darkness, though a few known varieties use sunlight as the source of energy to perform important life processes. But direct sunlight, as well as high temperatures and certain germ-killing substances called antiseptics, or germicides, kill most of them in a short time. Even those that produce spores are killed by exposure to sunlight for a few hours. The temperature at which growth and reproduction are most rapid varies with the particular kind of bacterium, but is usually from 20° C. to 40° C. Low temperatures check the growth of bacteria, though some forms are able to remain alive at extremely low temperatures. Most forms are killed at boiling temperature (100° C.).

Practical applications of the knowledge of conditions influencing the growth of bacteria are illustrated in food-preserving. In canning, the bacteria in the food are first killed by heat. The can is then sealed so that live bacteria cannot enter. In drying, water is withdrawn from the food, which is then kept so dry that bacteria cannot multiply in it. In salting, the bacteria are mostly killed because the salt causes osmosis of water out of the bacterial cells. In pickling, substances are added which are harmless to human beings but which prevent the rapid multiplication of bacteria.

Every bacterium consists of only one cell, though often many bacteria are found joined together to form what is called a colony. Each bacterium, however, whether by itself or one of a numerous

colony, must carry on all the life processes in order to live. It must get food, take in oxygen, get rid of wastes, grow, and reproduce.

***Useful and harmful bacteria.** Bacteria cause most of the diseases of plants and animals. For this reason we are inclined to think of their activities as being only harmful to man and his work. This is not the case. More than a thousand kinds of bacteria are now known, and of these only a few are parasites of man and the higher animals, and still fewer can cause disease. Most of the rest are harmless, while some are definitely useful.

Certain of the bacteria of decay are used in some of the industries. In the sponge industry, for example, the decay bacteria eat the softer tissues from the skeletons of the sponges. In the tobacco industry decay bacteria help in curing the leaves. In the flax and hemp industries decay bacteria eat the softer portions of the plant stems, leaving the tougher fibers, which are used. In the dairy industry certain other bacteria help in the preparation of butter and cheese. Still other bacteria aid in the cider and vinegar industry. It is difficult to realize that the "gamy" flavor which many people enjoy in meat and the delicate flavors of butter and certain cheeses are due to the beginning stages of decay.

Certain bacteria are useful in purifying sewage. These bacteria oxidize organic wastes and thus make them harmless.

The harmful bacteria, aside from those which produce diseases, are chiefly those which eat our foods and thus compete with man for the available supply of energy. These may excrete into the food chemical compounds which give the food an unpleasant odor or flavor or which in some cases may make the food poisonous.

***Yeasts.** Yeasts are single-celled plants considerably larger than bacteria, yet not large enough to be observed without the aid of a microscope.

Experiment 30. What is the appearance of the yeast plant? Dissolve a compressed yeast cake in a cup of water to which a tablespoonful of sugar has been added. Let it stand overnight in a warm place. Place a drop of the solution on a slide and examine it under the microscope. Make a sketch of any single yeast cells or groups which are distinctly different from those shown in Fig. 85.

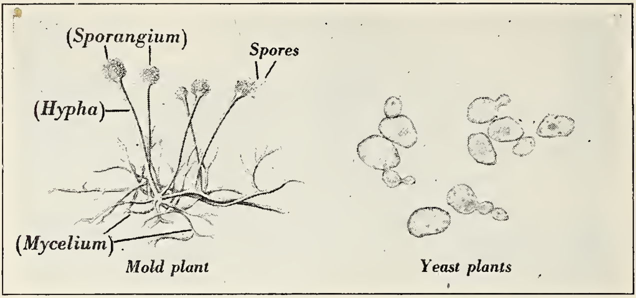


Fig. 85. In what sense do mold plants and yeast plants compete with man for energy?

The fact that the chief source of energy for yeasts is sugar makes these plants at times useful and at other times harmful. Alcohol and carbon dioxide are products of the action of yeasts upon sugar. This action is called fermentation. Alcoholic drinks, some of which have a definite place in medicine, are produced by the fermentation of fruit juices and of sugars produced from certain plants and grains. Bread is made light and porous by the escape of carbon dioxide, which is given off during the process of fermentation in the dough.

Yeasts do some damage when they cause fermentation in such foods as jellies, preserves, canned fruits, and sirups. The activities of yeasts sometimes produce a bitter taste in cheese and milk.

***Molds.** Molds are more complex than the other fungi we have studied. They are of great importance because (1) some varieties aid in the decay of wood and other substances, making the material available as foods for other organisms; (2) others compete with man for food energy (not only do they slowly consume it, but some species also give it an unpleasant odor or flavor or an unpleasant appearance); (3) others impart desirable flavors to certain cheeses; (4) still a few others cause diseases of man and of some of the other animals.

Experiment 31. What are the parts of a mold plant? Examine with a magnifying glass a moist piece of bread or a culture of agar-agar upon which mold is growing. Note the filaments (hyphæ) at the ends of which are the spore cases, or sporangia, containing the spores. Exam-

FIG. 86. *A*, an edible mushroom (*Lentinus lepidus*)[1]; *B*, a growing mushroom. Can you explain how it develops?

ine the sporangia to see whether you can find any of the tiny spores. Carefully separate the bread or the agar-agar culture to see whether you can learn what the parts of the mold beneath the surface are like (Fig. 85). Make a sketch showing the parts of a mold plant.

***Mushrooms.** Among the largest and most complex of the fungi are the mushrooms. They are common in woods and fields, where they grow as saprophytes on decaying wood and on decaying vegetable matter in the soil. A few grow as parasites on living trees. The real body of the mushroom is made up of a network of filaments (mycelia), or exceedingly small threads, extending through all portions of the food material. The part above ground has for its only purpose the production and scattering of the spores from which the new mushroom plants grow.

[1] From a photograph by William E. Sherwood. Courtesy of the *Nature Magazine.*

Some mushrooms are prized as food (Fig. 86), while others are more or less poisonous. A few are deadly. There are no tests which can easily be used to determine which are edible and which are not. It is safe to eat only those which somebody who knows them to be wholesome has taught you to recognize. There is grave danger in eating any others.

Self-test on Problem IX–A. **1.** Name the kinds of plants that are included in each of the four plant phyla.

2. Algæ in order to *thrive* must live in *dry* places.

3. *No* algæ are independent plants.

4. The source of *all* the food eaten by sea animals is *fungi.*

5. The smallest known plants are *yeasts.*

6. *No* molds are *harmful.*

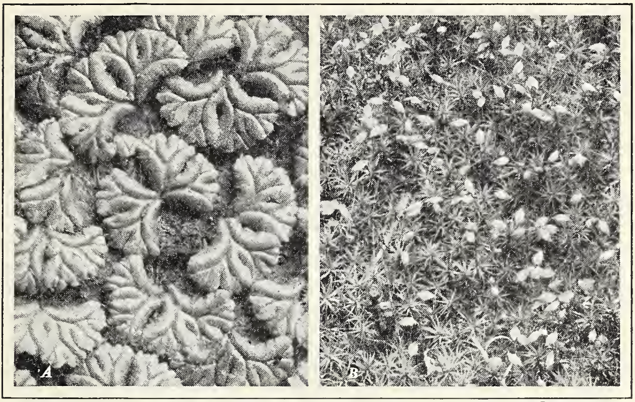
7. You can eat a mushroom with safety provided (1) it peels; (2) you know that species is good to eat; (3) it does not cause silver to turn black when it is boiled with the silver; (4) it has a pleasant smell; (5) it has a pleasant taste.

8. The conditions necessary for the rapid growth of bacteria are --(?)--, --(?)--, --(?)--, and --(?)--.

9. *No* bacteria are helpful to man.

Problem IX–B · What are Some Adaptations of Mosses and Liverworts (Phylum Bryophyta) which Enable them to Compete successfully for Energy?

Mosses and liverworts. Mosses and liverworts make up the second phylum (Bryophyta). They grow mostly on the ground, but many of them are found growing on tree trunks and dead logs. They are, however, all independent plants; that is, they possess chlorophyll and make their own food by photosynthesis. They rarely become more than two or three inches tall. Many of the small mosses grow in crevices on rocks or in shallow soil that will not support larger plants. The liverworts (Fig. 87, *A*) and some mosses are also found in water and on very wet soil. The common liverworts are flat dark-green plants, found in damp shaded places. They often spread from a single plant, forming a



L. W. Brownell

FIG. 87. Is either the liverwort (A) or the moss plant (B) a parasite or a saprophyte? Justify your answer

solid mat on the ground or upon old tree trunks or banks. Upright stalks for reproduction grow from the flat portions of certain varieties.

Experiment 32. What are the characteristics of a moss plant? Examine the plant to see whether you can discover stems, leaves, and the rootlike hairs. Does your specimen have spore cases on the ends of stems? Record your observations by means of sketches.

*A moss plant has a stem, small green leaves, and rootlike hairs (rhizoids), which anchor the plant and absorb moisture (Fig. 87, *B*). In these respects mosses resemble higher plants. They lack, however, true veins to conduct the water through the stems and leaves. They differ also from higher plants in lacking woody tissue for support. Moisture passes by osmosis from cell to cell throughout the plant. Both mosses and liverworts reproduce by spores rather than by flowers and seeds. The process of reproduction will be discussed in Chapter XXX.

***Importance of mosses.** Mosses are important plants, especially in relation to soil production and conservation. They will grow on rocks to which a very thin layer of soil clings. Their

rootlike processes force their way into the tiny pores in the rock, and as they grow tend to split off small pieces of the rock. When the moss plants die, their decaying bodies are added to the soil. Thus, over a long period of years, the mosses may so change a barren rocky surface that larger plants will be able to live there. Besides aiding in soil formation, mosses cover much of the floor of a forest with a heavy carpet that prevents the earth from washing away and that lessens the evaporation of moisture from the ground. Certain of the mosses (peat mosses, or sphagnums) which grow in swampy places may finally fill up the swamp, thus adding to the land surface, on which other plants will then grow. These mosses may form layers of material called peat, which will burn as coal does. One authority estimates that there is enough peat in the United States to supply our fuel needs for a century.

Self-test on Problem IX–B. **1.** *Some* of the mosses and liverworts are saprophytes, and *some* are parasites.

2. Moisture passes from cell to cell in the moss by the process of __(?)__.

3. *Mosses* are of great importance as makers of soil.

4. *Liverworts* are of great importance as a source of peat for fuel.

5. Liverworts are *sun-loving* plants.

Problem IX–C · What are Some Adaptations of the Ferns and their Relatives (Phylum Pteridophyta) which Enable them to Compete successfully for Energy?

***The ferns and their relatives.** These plants resemble the bryophytes in that they reproduce by means of spores. But they mark a higher stage of plant development in having roots, stems, and leaves, with the beginnings of vascular stem structure. They appeared on the earth before the flowering plants existed and were very large and abundant forms. During the coal-forming period of the earth's history fernlike plants were the dominant type of vegetation. Huge tree ferns formed vast forests over parts of North America and Europe.

The three groups of pteridophytes commonly found in North America today are the ferns, the club mosses (Fig. 88, *A*), and the

L. W. Brownell

FIG. 88. *A*, club moss, and *B*, scouring rushes. Can you name any relatives of these plants?

equisetums, or horsetails, also called scouring rushes (Fig. 88, *B*). Ferns are usually found in moist woodlands where the soil is rich and deep. They vary considerably in form, yet can usually be distinguished from one another by the differences in their feathery leaves. These arise from stems which are generally underground (rhizomes). Common ferns of the temperate zones vary in size from small lowly plants to slender graceful plants six feet or more in height. In the tropics and in Australia tree ferns may reach a height of more than forty feet (Fig. 89).

The club mosses, sometimes called ground pines, are small graceful plants. The commonest genus (*Lycopodium*) is extensively used in decorations at Christmas time throughout the United States. Fossil ancestors of club mosses with trunks more than ninety feet long have been found.

The ancestors of the scouring rushes, or horsetails, were tree-like plants which flourished in great numbers ages ago. Only one genus remains today. It is a jointed plant which grows in marshy ground, in sandy wastes, and along the embankments of railroads. It gets its name of scouring rush from its hard, rough, glassy stem,

U. S. National Park Service

FIG. 89. Fern jungle, Hawaii National Park. How do you explain the fact that tropic ferns are so much taller than those of the temperate zones?

which was formerly used in scouring cooking utensils. The genus *Equisetum* varies in height from about eight inches to about thirty feet for certain South American species. These latter sorts, however, are only an inch or so in diameter.

Self-test on Problem IX–C. **1.** The ferns as well as the mosses reproduce by means of *seeds*.

2. The fern plants grow from underground *roots*.

3. The ancient ancestors of the ferns and their relatives were *very small* as compared with the varieties now living.

4. One would expect ferns and their *relatives* to grow *larger* in Mexico than in Canada.

Problem IX–D · What are Some Adaptations of the Seed-Bearing Plants (Phylum Spermatophyta) which Enable them to Compete successfully for Energy?

The highest plants. The plants which belong to the fourth phylum (Spermatophyta) differ from those of the groups previously studied in the fact that they all produce seeds. In one

division of the spermatophytes, the gymnosperms, the seeds are usually borne in cones. In the other division of the spermatophytes, the angiosperms, the seeds are developed within certain parts of a flower and are inclosed in some sort of pod, case, or nut.

Gymnosperms. The cone-producing plants (gymnosperms), or conifers, are represented in this country by such trees as the pines, spruces, hemlocks, and sequoias. Most of them are evergreens with needlelike leaves. The cones are of two sorts, those producing pollen (staminate cones) and those producing the eggs (pistillate cones). The seeds develop from the fertilized eggs, which are borne on the scales that make up the cone.

Angiosperms. The angiosperms are the true flowering plants, in the sense in which the word *flower* is commonly used. There are over two hundred thousand kinds of known angiosperms. These vary enormously in size from that of certain water plants, the duckweeds, which are no larger than small pinheads, to the giant stature of the big trees of the Pacific slopes. Angiosperms range in length of life from that of certain desert plants which grow, produce flowers and seeds, and return to dormancy following a favorable rain to that of trees that may live for thousands of years, growing and producing new seed crops from year to year. The flowers show a remarkable range in size, color, and odor, from those which are microscopic and without color or odor to others which are more than a foot long, are brilliantly colored, and have odors that may be carried long distances. All flowers show the same essential structure.

Flower structure. ***Experiment 33.*** What are the parts of a typical[1] flower? You may use any simple flower, such as apple, tulip, lily, petunia, violet, buttercup, or morning-glory (Fig. 90). Look near the stem for the outer row of green leaflike parts, the *sepals.* (If you are using a tulip or lily, these parts are colored like the next row.) All the sepals together make up the *calyx.* The brightly colored *petals* are the most conspicuous parts of most flowers. How many petals has your flower? Is the number the same as the number of sepals? When the petals are spoken of together, we call the structure a *corolla.* Inside the corolla find the *stamens,* which are slender stalks with knobs, called

[1] *Typical* (tip'i kal): characteristic, illustrating a type.

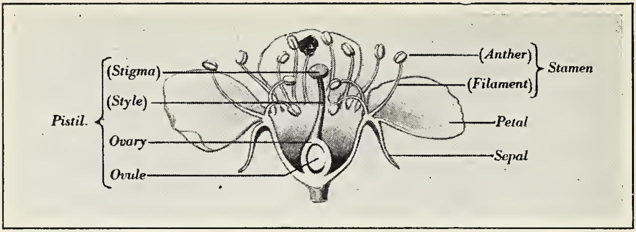


FIG. 90. Do all flowers have all the structures shown here? What structures of the ferns and mosses have the same function as the seeds of flowering plants?

anthers, at the tip. How many stamens are there? Touch an anther with your finger. The powder which comes off is *pollen.* Examine some of the pollen under a microscope. Make a sketch showing the shape. In the center of the flower is the *pistil.* By comparing your specimen with Fig. 90 identify the *style* and *stigma* and *ovary,* which are all parts of the pistil. With a knife or razor blade cut across the ovary. The small round structures are *ovules,* which may develop into seeds. Make a diagram which will show the parts of a flower as you find them in the flower you are studying.

Fruit structure. ***Experiment 34.*** What evidences of the parts of the flower are found in a fruit? Use green beans or peas. Can you find on the pod any remains of the style and the stigma? Can you find the calyx? Open the pod. What structures are found in it? From what part of the flower must this pod have developed? Any structure developed in such a manner is called a fruit. Answer in a complete sentence the first question in this experiment.

Monocotyledons and dicotyledons. In Chapter VI differences in monocot and dicot stems were discussed. The differences in seeds, flowers, and leaves are more easily observed than are the differences in stems, and serve as a ready means of distinguishing the two groups.

*The flowering plants are thus divided into two groups, monocotyledons and dicotyledons. This distinction will be clear from a study of the two types of seeds.

Experiment 35. What is the structure of a typical dicot seed? Soak lima beans or kidney beans overnight. How do the soaked beans compare in size with dry ones? On one side find the scar (hilum) where the seed was attached to the pod. Near one end of this scar is a tiny

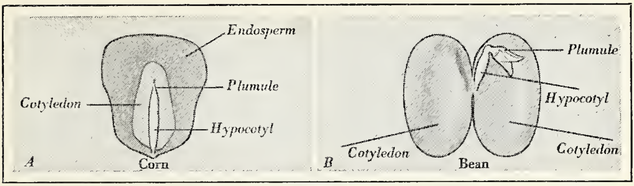


FIG. 91. *A*, corn seed (monocotyledon); *B*, bean seed (dicotyledon). Compare these two seeds; also compare Fig. 91 with Fig. 61, p. 101 (see "Suggestions for Effective Study," p. xvi)

opening (micropyle). This opening permitted the entrance of the pollen tube when the egg which produced the seed was fertilized. It also serves to admit water. Now remove the seed coat (testa). Note the two halves into which the bean separates readily. These are the cotyledons. Because there are two of them, the bean is called a dicotyledon, or dicot. Break the cotyledons apart carefully (Fig. 91, *B*). Near one end you will find two tiny leaves, the plumule — and a rodlike structure called the hypocotyl. The plumule will form the stem and leaves, and the hypocotyl will form the roots. The cotyledons, plumule, and hypocotyl together form the embryo, or undeveloped plant. Make a sketch which will show the parts of the bean seed. Label your diagram in accordance with Fig. 91.

Experiment 36. What is the structure of a typical monocot seed? Soak corn grains overnight or longer. As you examine a grain, do you note a light-colored region on one side? This is the embryo. Cut a grain in two lengthwise and stain one half lightly with iodine. The part which colored most deeply is the stored food (endosperm) which the embryo plant uses in its earliest growth. The rest of the inside of the grain is the embryo. You will find that the corn embryo has parts (Fig. 91, *A*) which correspond to those of the bean. What is the position of the hypocotyl? The single cotyledon lies against the stored-food region. Because it has only one cotyledon in its seed, the corn is called a monocotyledon, or monocot. Make a sketch of the corn grain cut lengthwise.

Experiment 37. 1. How does a seed grow to produce a plant? Plant six or more soaked bean seeds and the same number of corn grains in wet sand or sawdust. Dig up and examine one seed of each kind every day. When does the seed coat first break? What part of the embryo first comes through the coat? What part of the seed first comes above ground? What becomes of the cotyledons? What is their use? Make sketches from day to day to show your observations. Label

cotyledons, plumule, and hypocotyl. What seems to be the use of each part of the seed in producing the young plant? In what ways is the growth of a dicot seed like that of a monocot? In what ways different? (See Fig. 61, p. 101.) Make sketches to show the various stages of development.

Experiment 38. Is heat necessary for growth? Fill three flowerpots with sawdust, and plant in each a few bean seeds, corn grains, or other seeds. Moisten thoroughly. Put one pot in a very cold place, as out of doors or in a refrigerator; place the second near a radiator or stove where the temperature most of the time is about 95° F.; put the third in a room where the temperature is about 70° F. Keep the seeds moist and examine them after four days. In which of the pots have the seeds started to grow? In which pot do they grow best?

Exercise on scientific method (planning experiments). Plan experiments which will show whether or not water must be present for seeds to germinate and how much water is necessary for growth.

Experiment 39. What are the differences between dicot flowers and monocot flowers? Collect several kinds of common flowers, such as tulip, morning-glory, violet, trillium, lily of the valley, lily, geranium, gladiolus, or any others that are in bloom. Count the petals and the stamens of each flower. Put in one group those flowers that have petals and stamens in groups of three or six. These are monocots. The dicots have the petals and other flower parts in groups of four or five. Which of the flowers that you have are monocots? Which are dicots?

Not only can one find differences in the flowers, but also it is usually easy to distinguish the monocots from the dicots by the general forms of their leaves. The leaves of such monocots as corn, oats, lily, Easter lily, banana, and Solomon's seal may be compared with the leaves of such dicots as cottonwood, bean, oak, elm, hickory, and geranium. The monocots have leaf veins running parallel with the large middle vein, or midrib, and with one another to the leaf margin or leaf tip (Fig. 92). Microscopic veins connect the larger parallel veins. The dicots have a few large veins branching from the midrib, with many smaller veins branching through the leaf. Such leaves are called net-veined leaves. Monocot leaves usually have smooth margins, while dicot leaves may have margins which are toothed or lobed,[1] or the leaves

[1] *Lobe*: a rounded, projecting part or division of such a plant organ as a leaf or fruit, or a projecting part of an animal organ, which is not entirely separated from the rest.

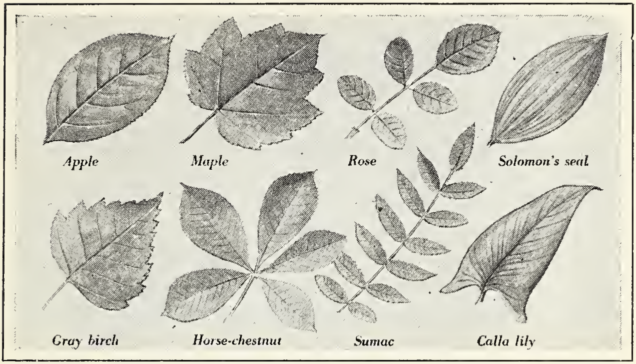


FIG. 92. Some typical leaf forms. Which are monocots and which are dicots?

may be compound, that is, made up of several similar parts. Monocot leaves usually have clasping leaf bases, while dicot leaves usually have petioles.

*__Summary of differences between monocots and dicots.__ Chapter VI and this chapter state points of difference between members of these two groups of flowering plants. A summary of these principal differences will be found convenient for reference.

Monocotyledons	**Dicotyledons**
Seeds	
One seed leaf	Two seed leaves
Stems	
Many vascular bundles scattered through the stem; not arranged in a single ring.	Vascular bundles arranged in a cylinder surrounding the pith. Vascular bundles separate in a young plant.
Leaves	
Generally parallel-veined; generally smooth margins; generally clasping bases.	Generally net-veined; frequently toothed, lobed, or compound; generally possess petioles.
Flowers	
Flower parts — stamens, pistils, and petals — usually three, six, or nine in number.	Flower parts — stamens, pistils, and petals — usually four or five or eight or ten in number.

Some important monocots. The monocotyledons include such important families as the grass family, the palm family, the lily family, the orchid family, and many others. The grass family contains all our important grains, such as wheat, oats, barley, and corn, as well as such plants as sugar cane and bamboo. Some members of the lily family are the tulip, lily of the valley, hyacinth, narcissus, onion, and leek.

Some important dicots. There are many more families of dicotyledons than there are of monocotyledons. Some of the more important families are given here. The rose family includes many plants such as cherry, apple, peach, pear, strawberry, raspberry, and rose, which have very different habits. The members of the legume family can be recognized by their irregular flowers, which resemble the sweet pea, and by their pods, which contain the seeds. Some legumes are pea, bean, clover, alfalfa, peanut, locust tree, and redbud tree. Some other large families, of which you may know one or more representatives, are the mint family, the buttercup family, the parsnip family, and the mustard family. The largest family of the dicotyledons is the composite family (Compositæ), of which dandelions, asters, sunflowers, dahlias, and artichokes are examples.

Experiment 40. How are the structures arranged in a composite flower? Examine with a hand lens a composite flower, such as a dandelion, sunflower, aster, or dahlia. Does it have more than one pistil? Notice how easily the entire flower will separate into smaller parts. Are these all alike? Look at one closely. Can you find the stamens? How many petals are there?

The flowers of the composites are usually small, but are grouped into a head, or cluster, which we commonly call a flower. Thus a dandelion "flower" is really a collection of small flowers.

Self-test on Problem IX–D. **1.** The seeds of the *angiosperms* are protected by flower parts.

2. The cone-bearing plants, the *angiosperms*, bear both male and female cones.

3. The *monocot* plants usually have leaves with branching veins.

4. *Monocot* leaves usually have *petioles.*

5. The grain plants are *dicots.*

6. Fruit trees, such as the peach and plum, are *angiosperms* and also *dicots.*

7. The family of flowering plants whose flowers are grouped together in one head are the __(?)__.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Why is water from deep wells likely to be practically free from bacteria, while that from the surface is likely to contain great numbers?

2. How can one keep molds from attacking foods and stored goods? Why does covering jelly with paraffin prevent molding?

3. Where are bracket fungi found? What are their characteristics?

4. What is a lichen? Of what importance are lichens?

5. Name from each phylum a plant of economic importance.

Project 5. Secure a tree guide and identify the conifers of your locality. Collect from as many as possible of these some cones that have not yet opened. When they are dry, the scales will open and expose the seeds. Make a record of the different kinds you identify, stating where each grows.

Project 6. Soak various kinds of seeds, such as peanut, sunflower, radish, pea, oats, and wheat. Examine them as you did the beans and corn. Classify the seeds as monocotyledons or dicotyledons. Make a record of those that belong in each group.

Project 7. Plant some of the seeds from a pine cone. Watch the plant closely as it comes through the ground. How many cotyledons are there? Explain why the conifers might be called polycotyledons.

Project 8. To find twenty or more monocots and twenty or more dicots which have not been mentioned in this chapter. Use the summary given on page 147 to distinguish monocots and dicots. Keep a record of your plants, naming each if you can find its name. State for each plant the characteristics which led you to classify it as either a monocot or a dicot.

Project 9. To identify twenty or more common wild flowers. Use a flower guide to learn to recognize members of our commonest families of flowers. Keep a record of those you identify.

Chapter X · The Simpler Animals

Questions this Chapter Answers

What are some characteristics of Protozoa?
How do sponges illustrate complete metamorphosis in their life histories?
How do sponges illustrate simple division of labor?
What are some characteristics of the hydra and its relatives?
In what respects do hydras illustrate a higher degree of division of labor than do the sponges?
What are some of the characteristics of flatworms?
Why is the tapeworm important?
What is the life history of the liver fluke?
What are some of the characteristics of roundworms?
Why is the hookworm important?
What is the life history of the parasite which causes trichinosis?
What are some characteristics of the starfish and its relatives?
What are some important facts about earthworms?
What are some of the characteristics of the clam and its relatives?
What are important functions of the structures found in these various animals?
Of what importance are these various groups of animals?

Problem X–A · What are Some Adaptations of the Simplest Animals (Phylum Protozoa) which Enable them to Compete successfully for Energy?

Protozoa are microscopic. There are countless animals which live all about us all our lives, but we are likely to remain unaware that they exist because they are too small to be seen with our naked eyes. With a microscope, however, we can invade their world and find out what many of them are like and how they live.

Experiment 41. What are the characteristics of some Protozoa? Put into a jar of water a little well-rotted barnyard manure, together with a handful of grass, and into another jar of water some pondweeds or hay. After four or five days in a warm place each of the jars will have a foul-smelling scum at the top. Put a drop of water from the surface of one of the jars on a slide and examine it under first the low-power and then the high-power objective of the micro-

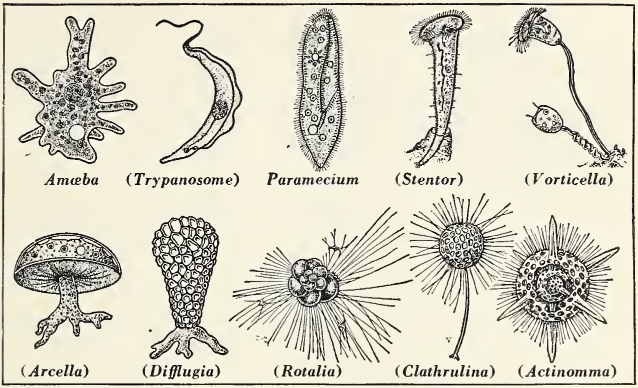


FIG. 93. Compare these Protozoa. The first five have no skeletons of any sort. The last five have skeletons of lime or silicon, or they have protective coverings of minute shells cemented together. There are about 9000 species of Protozoa

scope. Do you observe any animals moving about in the drop of water? Prepare another slide with a drop of water from the surface of the second jar. Are the animals which you observe in the second drop like those in the first? Make other slides from each jar. A small bit of cotton put under the cover glass will hinder the movements of the animals and will thus give you a better opportunity to observe them. How many different kinds of animals can you learn to recognize in the drops? Can you discover how they move about? how they eat? how they get past objects in their way? Summarize your findings in one paragraph.

Exercise on scientific method (making inferences). Can you explain how the Protozoa got into your culture?

*If you have performed this experiment, most of the creatures you have been studying were Protozoa. They are the lowest invertebrates[1] and also the simplest animals. Protozoa are to be found in almost every moist place. Many different species are known (Fig. 93), some living in fresh water, others in the ocean, some in damp earth, and still others as parasites in the bodies of many animals. Although the body of the protozoan consists of

[1] *Invertebrate* (in ver'te brate): the general name given to all animals which do not have backbones. *Vertebrates* (ver'te brates): the higher animals, all of which have backbones.

but a single cell, it performs all the life processes which every animal must perform. It eats, digests its food, and attains its growth. It responds to stimuli, such as light, heat, and vibrations in the water. It breathes and reproduces. Moreover, some forms of Protozoa are even able to fight their enemies.

Many Protozoa are able to survive even when the water in which they are living is entirely evaporated. They form about their bodies protective coverings called cysts. The protoplasm within the cyst remains alive but inactive. When the animal again becomes moist, it absorbs water and continues life as before.

Paramecium. The largest and probably the most numerous of the animals you found in Experiment 41 was the slipper-shaped *Paramecium* (Fig. 93). Some of this genus can be seen with the naked eye as tiny white specks that move about very rapidly.

The animal moves by the action of tiny hairlike projections (cilia) all over the body. These beat back and forth, like hundreds of tiny oars, and propel the animal in a spiral direction either forward or backward. There will be many references to *Paramecium* and other Protozoa in later chapters of this book.

Amœba. If in looking for Protozoa in Experiment 41 you were very fortunate, you may have seen an amœba, which looked like a piece of bluish-gray jelly moving slowly through the water. It represents the simplest sort of animal life known. It is not a free-swimming animal like *Paramecium,* but it moves about by crawling over the bottom in this peculiar way. As you watched it, you would see it changing shape constantly. First there would be a bulge on one side of the jellylike mass. This bulge would extend forward, and the rest of the animal would then flow into the projection. Thus a projection might form on any portion of the animal, and the animal would move about in the liquid by flowing into one projection after another.

Other Protozoa. Several rather common Protozoa look more like flowers than animals (Fig. 94, *B*). Such a protozoan is attached to some support by a stalk that either can be lengthened as the animal waves about in search of food or can be quickly contracted.

There are some members of this phylum which do not seem to fit the definition of Protozoa as one-celled animals. These forms live in groups, or colonies, and are therefore known as colonial

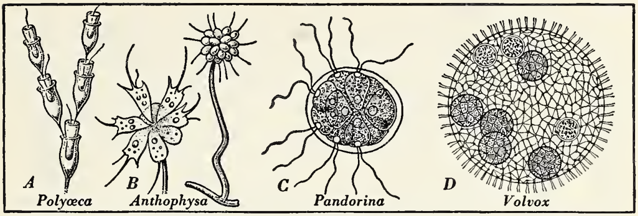


FIG. 94. Which of these colonies of Protozoa show indications of division of labor? Can you find a volvox in Fig. 79, p. 128?

forms. Usually the members of the colony are independent, each getting its own food and performing all other necessary functions. Some of the stalked forms look like a widely branching tree, each tiny branch of which is a separate animal (Fig. 94, *A*). Other species form colonies which take the shape of a sphere in which the separate animals are held in place by a jellylike substance (Fig. 94, *C*). In *Volvox* (Fig. 94, *D*), a rather large colonial form, there are threads of protoplasm connecting one animal with another. The members of this colony are not really independent, as are the Protozoa which have already been described. Moreover, the member cells of the colony are not all alike. Only certain ones of the cells are able to reproduce. These cannot capture their own food or help in moving the colony about. They share by osmosis the food secured by neighboring cells which cannot reproduce. The animals of this colony, therefore, show the first indications of division of labor, though not true division of labor, as will be shown later.

Like most of the one-celled plants most of the one-celled animals have no skeletons of any sort. One large group, however, have shells of lime and other minerals (Fig. 93). When such animals die, these shells drop to the bottoms of the lakes or seas. In the course of time they become pressed together to form hard layers. In this way certain kinds of common limestone have been formed. The chalk cliffs of Dover, England, were formed in this way ages ago. The warping and folding of the earth's surface finally, after millions of years, resulted in forcing these layers above sea level.

***Economic importance.** Protozoa are important to man in several ways. Many of them serve as food for young fish. Others are eaten by slightly larger animals, which in turn serve as food for fish. Certain others, living as parasites in man and other animals, cause serious diseases.

Further discussions of Protozoa will be found in later chapters of this book.

Self-test on Problem X–A. 1. A common protozoan which has no definite shape is *Paramecium.*

2. *None* of the Protozoa have protecting structures.

3. Indications of division of labor are noted in the __(?)__.

4. Certain diseases are caused by Protozoa which live in the body as *saprophytes.*

5. *Fish* serve directly or indirectly as food for *Protozoa.*

6. Protozoa have existed on the earth probably for *hundreds* of years.

7. *Water* is necessary to the existence of *few* Protozoa.

Problem X–B · What are Some Adaptations of the Simplest Many-Celled Animals, the Sponges (Phylum Porifera), which Make them Successful Animals?

Sponges live both in fresh and in salt water. If you have been fishing or swimming in a stream or pond, you may have seen fresh-water sponges. They form patches of gray or green, usually less than an inch thick but often covering several square inches, attached to stones or sticks in protected places. These patches have the appearance of being plant life. The green color of some of them suggests chlorophyll, making them seem all the more like plants. When the masses are examined closely, however, the green color is usually found to be due to algæ on the surface.

*The sponges are the lowest Metazoa, that is, animals having bodies composed of many cells (Fig. 95). They mark the next step in the scale of life above the Protozoa. Fresh-water sponges are found in rivers, lakes, and canals in all parts of the world. Marine, or ocean, sponges are found in all the seas and at all depths, from the shallow water along the shore to the deepest abysses. Sponges vary widely in form and range in size from that

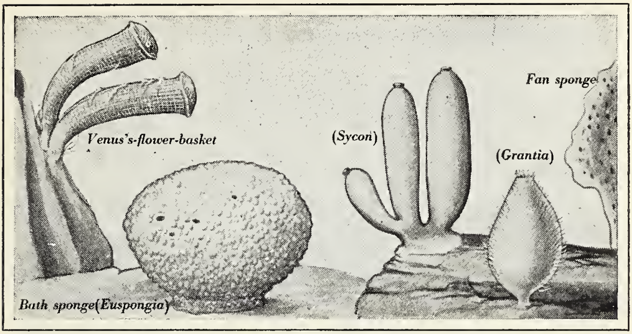


FIG. 95. Not all the marine sponges shown here live in the same locality or at the same depth. There are at least twenty-five hundred species of sponges. What is meant by the statement "The sponge is a successful animal"?

of a pinhead to almost the height of a man. While most sponges are white or gray, others are colored with all the hues of the rainbow.

Structure of sponges. Sponges are relatively simple in structure. The body, which is generally tubelike, consists of two distinct layers of cells. The outer layer is of rather large bricklike cells which form a covering for the rest of the body. The inner layer is very similar, forming a covering for the inside of the tube. Between these layers is a jellylike region. Scattered through this are wandering amœba-like cells.

Sponges have skeletons of a tough silklike material (spongin) or of a glassy substance, forming a network all through the body. In the sponges, as in many others of the simpler animals, the skeleton serves chiefly to protect from enemies the soft parts of the body.

Water enters through numerous openings, or pores, in the body wall of the sponge and passes out through a large opening at the end. A continuous current of water is created by the movement of whiplike structures (flagella) which project from the cells lining the inner cavity. This stream of water brings to the animal oxygen and food which consists of microscopic plants and animals and other organic particles.

Metamorphosis. The adult sponge is always attached to a stone, a stick, or some other object. The young sponges, or larvæ, however, swim freely and do not resemble the adult sponges (Fig. 96). When an animal goes through two or more stages in developing from the young to the adult form, the animal is said to undergo a *metamorphosis*.[1] If the change from one stage to the next is abrupt and if the animal in each stage appears to be entirely different from the same animal in the preceding stage, the metamorphosis is said to be a *complete metamorphosis.* The sponge is the simplest animal having a complete metamorphosis in its life history. Many examples of complete metamorphoses of more complex animals will be found in later sections of this book.

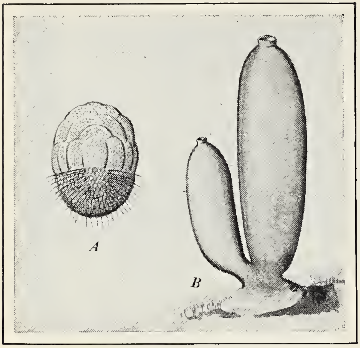


Fig. 96. Explain how these drawings illustrate the complete metamorphosis of the sponge. The larva *A* is very small compared with the adult form *B*

Division of labor. With some of the colonial forms of Protozoa, as has been explained, different kinds of cells carry on certain functions, such as food-getting or reproduction. Each profits to some extent from the activities of the others; yet the food-getting cells *could* live independently, that is, without help from other cells.

The sponge, however, not only marks an advance in complexity[2] of structure over the Protozoa, but also, because of this increased complexity, it shows a true division of labor. Thus the cells along the inner cavity of the sponge do the work of food-getting and digestion for all the cells. Other cells of the inner layer secrete

[1] *Metamorphosis* (met a mor′fo sis): the changes in form and appearance which certain animals undergo in developing from the egg to the adult. Plural *metamorphoses.*

[2] *Complexity* (kom plex′i ty): state of being complex, that is, the opposite of simple. *Complicated* (kom′pli kat ed): complex, or the opposite of simple.

Fig. 97. Nearly a million dollars' worth of sponges a year are marketed at this port, Tarpon Springs, Florida. Special Report: Describe sponge fishing and the preparation of sponges for market. (Consult a college textbook of zoology or an encyclopedia)

the material that forms the skeleton. Those on the outside serve as a protective covering for the inner cells. No single sponge cell could live independently, nor could the cells in one layer live without the help of the cells either in the other layer or in the jellylike region. Yet every small group of cells which includes some cells from each of the layers can together perform all the functions necessary to life. The sponge, therefore, illustrates in the simplest way the biological principle that every cell of a metazoan takes part in the division of labor, that is, every cell has certain work to do for the survival of the whole animal.

***Importance of sponges.** Few animals use sponges as food, but many animals, such as worms, insect larvæ, and crustaceans, may seek shelter in the pores and hollow bodies of sponges. None of the fresh-water species are of value to man, but the skeletons of several species of marine sponges are used as bath sponges, for the padding of coats, and for a variety of industrial and household purposes. The best bath sponges are secured from Florida (Fig. 97) and Cuba, the Mediterranean coast, Australia, and the Bahamas.

Vacation-Time Biology

Of THE many new animals we saw on our first visit to the ocean, none held us more entranced than the jellyfish. The ocean that first evening seemed fairly alive with them. They gave off flashes of light here and there, streaks of color in the wake of a passing boat, or a steady glow where they had collected about a log that was drifting offshore. We couldn't leave such beauty even for the night. So we dipped out a few of the fascinating animals and carried them home.

For an aquarium we used an old washtub in which the jellyfish, which were three or four inches across, swam about with a movement somewhat like the opening and closing of an umbrella. For several days we enjoyed them. Then one morning we found them floating on the surface, almost dead. The water was cloudy, too, as if they had already begun to decompose. We had about decided to empty the tub when someone who had dipped out some of the water in a glass noticed specks moving about. Could they be young jellyfish? We looked again at the old jellyfish. The egg sacs, which had been the most conspicuous parts of their bodies, were now small and wrinkled. That was evidence enough. The eggs had been laid in the water and had hatched overnight into thousands of little jellyfish. We filled other glasses with the cloudy water.

After breakfast we returned for another look at the little jellyfish. But something had happened! The water was no longer cloudy. Where were those thousands of little jellyfish? We held a glass up to the light and looked closely. There they were, small, transparent lumps of jelly fastened to the glass. With a magnifying glass we could see that they were alive. Now came another surprise. By the next morning those small lumps of jelly had developed arms, four of them, stretching out from the top. The little animals looked much more like flowers than like jellyfish. Apparently young jellyfish do not resemble their parents. Father said we really should now call them hydroids. In a week they had grown to be a quarter of an inch long, and many of them had more than four arms. We could now see plainly that the arms were meant for work. They reached out and swept particles of food into the mouth, which was in the center of the circles of arms. But that was all our hydroids did for weeks —just eat and grow.

Then one spring morning our next surprise came. The hydroids stopped eating, a fact that made us suspect that something new was about to happen. We examined them closely. Each, now about half an inch long, looked as if pieces of string had been tied tightly about it in six or eight places. The furrows thus made became deeper and deeper, until each hydroid looked like a pile of very shallow cups. The arms became shorter, then disappeared.

Soon the upper cup started moving, jerking back and forth and up and down. Finally it broke loose from the rest of the pile, turned itself over, and swam away. It was a jellyfish, very small but otherwise like the first ones we

had found. One by one the rest of the cups followed the example of the first, until the water contained hundreds of little jellyfish swimming about. Father

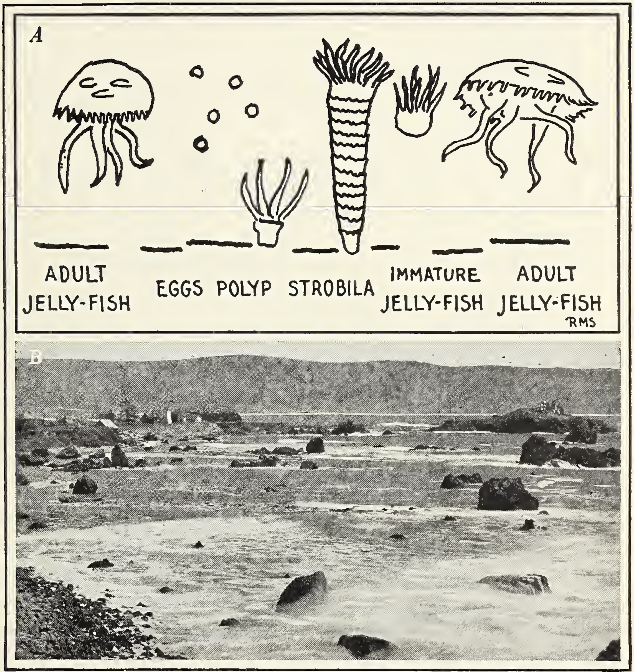


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Fig. 98. The drawing is copied from a vacation-time notebook. Can you explain how it shows alternation of generations? The photograph is of the shore, where were found many interesting specimens for a biology museum

said they would grow to be adult jellyfish. These would lay eggs which would again develop not into jellyfish but into hydroids. Thus hydroids would produce jellyfish, and jellyfish would produce hydroids. We had observed the "alternation of generations" in the jellyfish-hydroid family. Later we learned of many other organisms which have alternation of generations in which, as Tom remarked, "the babies look exactly like their grandparents, but not a bit like their parents."

Self-test on Problem X–B. 1. Sponges (1) are plants; (2) live only in the ocean; (3) live both on land and in the water; (4) live both in fresh water and in the ocean; (5) live only in fresh water.

2. The simplest Metazoa are *Protozoa*, having bodies made up of many cells.

3. The body of the sponge is made up of *three* layers of cells.

4. In developing from the larva into the adult sponge the animal undergoes a *complete metamorphosis*.

5. *Few* of the individual cells of the sponge could live alone.

6. The simplest animal in which there is true division of labor is (1) *Volvox*; (2) a sponge; (3) *Paramecium*; (4) *Pandorina*; (5) *Amœba*; (6) a liverwort.

7. The only part of the sponge which is useful in industry is its __(?)__.

Problem X–C · What are Some Adaptations of the Hydra and its Relatives (Phylum Cœlenterata) which Make them Able to Compete successfully for Energy?

Animals that look like plants. The corals, sea anemones, jellyfish, and fresh-water hydras all belong to the group of cœlenterates. All these animals are found in the water, most of them in the ocean. They are often beautifully colored and vary greatly in form (Fig. 99). With the exception of the jellyfish and a few related forms, they are all attached to rocky bottoms, and occur in such great abundance that the ocean floor of the warmer seas looks like a garden of many-colored plants. Their branching habit gives them an added resemblance to plants, and it is not strange that they were first so classified.

***Characteristics of cœlenterates.** These animals have bodies that are essentially two-layered bags. They have no right and left sides, but are made up of like parts arranged around a common center. Thus they are radially symmetrical; that is, if they were divided in two from top to bottom along any diameter (for example, as one would cut across a pie), each half would be like the other. The jellyfish perhaps shows this structure best. The animals in this phylum mark a higher stage of development than do the sponges, in having a single opening into the body, and a central cavity in which digestion takes place.

FIG. 99. A group of marine cœlenterates. *A*, a coral-like form (*Gorgonia*) ; *B*, two sea dahlias (*Tealia*), one capturing a prawn; *C*, a sea gooseberry (*Pleurobrachia*) ; *D*, a jellyfish (*Aurelia*) ; *E*, a coral-like form (*Sertularia*) ; *F*, a jellyfish (*Haliclystus*) ; *G*, sea anemones (*Metridium*). From a study of the text, in what respects should you expect all these cœlenterates to be similar? There are about forty-two hundred species of cœlenterates

Hydra. Those of us who live far away from the sea have little opportunity to see jellyfish and sea anemones alive. But we can study a very common little cœlenterate found in nearly all our small lakes and streams. It is *Hydra*, an interesting animal about a quarter of an inch long, either green or brown in color (Fig. 100). It is usually found attached to the leaves or stems of water plants.

*If a hydra is removed from the water, it shrinks into a shapeless mass of protoplasm, but when returned to the water it resumes its usual appearance. This behavior tells us that the body is not supported by a skeleton of any sort, but depends on the water to hold it up. The body is indeed a cylindrical bag, with one end attached to some solid object and with a mouth surrounded by tentacles (usually six in number) at the other end.

Most of the time *Hydra* remains attached, and the only movements are a stretching and a contracting of its body and a

waving of its tentacles. But it has several ways in which it can move slowly from place to place. One method somewhat resembles that of a measuring worm. It bends its body over until its tentacles touch a support; then it lets go with its "foot" and literally stands on its head. Then its "foot" is attached again, and its tentacles are straightened upward. A second method, which however, it rarely uses, is to walk on its tentacles as if they were legs. Besides these methods of locomotion *Hydra* often slides along on its "foot," much as a snail does.

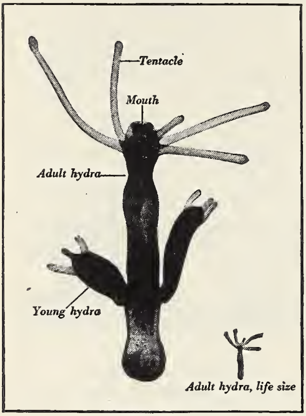

FIG. 100. You can find hydras in almost any fresh-water pond or stream. The smaller drawing is life size. Is *Hydra* a parasite? Justify your answer

Division of labor is more highly developed in *Hydra* than in the sponge. The body of *Hydra* is made up of cells arranged in two layers. Yet simple as this animal is, it nevertheless possesses several kinds of highly specialized[1] cells. The outer layer (ectoderm) is primarily for protection. It contains (1) muscle cells, which enable the animal to expand and contract and to move about; (2) stinging cells, which aid in securing food and warding off enemies; (3) nerve cells, which respond to light and other stimuli. In addition certain of the cells may become modified to carry on reproduction. The cells of the inner layer (endoderm), like those of the sponge, are concerned with digesting food for the whole animal.

Corals. The individual coral animals (polyps) are very much like the hydra. They live in large colonies, and each animal builds up around its tubelike body a skeleton of carbonate of lime, into which it can withdraw when necessary. Coral masses differ greatly in form, some being slender and branching and others rounded and smooth (Fig. 101). The colony increases in size by

[1] *Specialize* (spesh'al ize): to prepare or set aside for some special purpose.

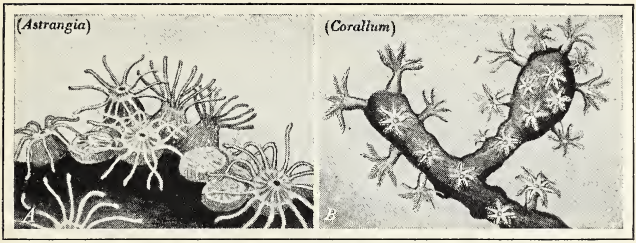

FIG. 101. Of these coral colonies, *A* is common along the North Atlantic coast and *B* is a precious coral. How many relatives of the coral can you name?

budding from the bases of the older animals. Little by little a great mass of rocklike material is built up by succeeding generations of coral animals. In this way over long periods of time corals have added much land to the margins of continents (Fig. 102).

Economic importance. The cœlenterates are of relatively little importance to man. The skeletons of some corals are used

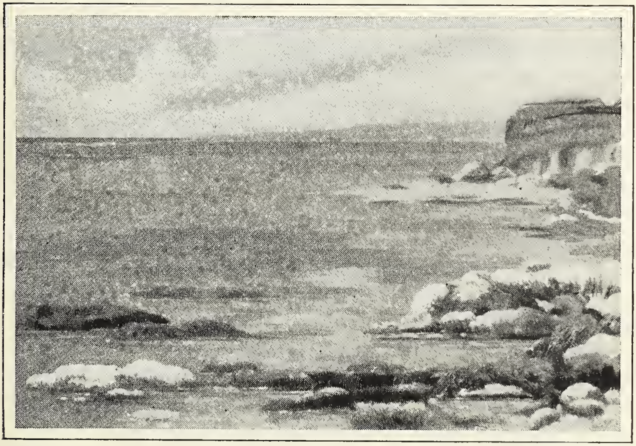

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FIG. 102. The site of Chicago about four hundred million years ago was a coral reef looking somewhat like this picture. At that time the region was covered by an arm of the Arctic Ocean. From the fact that corals grew in the water do you think the water was then cold or warm?

for jewelry. Jellyfish are eaten by fish and whales; but since their bodies are 99 per cent water, they do not furnish much real nourishment.

Self-test on Problem X–C. **1.** *All of* the corals and their relatives are free-swimming forms.

2. The cœlenterates mark a higher stage of development than the sponges because (1) they have a two-layered body; (2) they look more like flowering plants; (3) they live chiefly in the ocean; (4) some of them have no skeletons; (5) they have a single mouth and a single digestive cavity.

3. The hydra represents a *higher* degree of division of labor than the sponges because it has more different kinds of cells with different functions.

4. The cœlenterates are of *great* economic importance.

5. *Hydras* live in great colonies.

Problem X–D · What are Some Adaptations of the Flatworms (Phylum Platyhelminthes) which Enable them to Compete successfully for Energy?[1]

Wormlike animals are not always true worms. Worms are likely to be thought of as being among the common animals. Furry caterpillars in great numbers crawl on the sidewalks or trees in the spring and summer. Worms of various sorts feed upon the flowering plants and vegetables in our gardens. Numerous earthworms are seen on the walks and in puddles after heavy rains. Centipedes are found under boards. A careful study of these various "worms," however, shows that most of them are not truly worms at all. The caterpillars, cabbage worms, tomato worms, apple worms, and other "worms" of this type are the larvæ of certain insects and will later develop into moths, butterflies, or other insects. The centipedes, in spite of their wormlike appearance, are not even closely related to true worms, but are near relatives of the insects, crabs, and spiders.

We are not likely to be familiar with many types of true worms because many of them live in the ocean, many others live in the ground, and still others live as parasites in the bodies of other

[1] To the Teacher. Certain phyla are omitted from this discussion because the animals composing them are relatively few and unimportant and are familiar to few except zoölogists.

animals and plants. The true worms make up three phyla of the animal kingdom: (1) the flatworms (Platyhelminthes), such as tapeworms; (2) the roundworms (Nemathelminthes), such as hookworms and the horsehair snakes; (3) the segmented worms (Annelida), such as earthworms. Of these true worms the annelid is much higher in the scale of life than the flatworm and the roundworm.

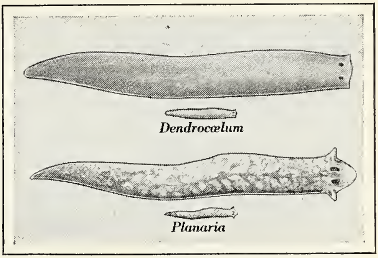


Fig. 103. The smaller drawings beside the larger ones of these two common flatworms show actual size of these animals. Special Report: How many species of flatworms are known? (Consult an advanced zoology textbook or an encyclopedia)

Characteristics of flatworms. Most flatworms have bodies which are soft, thin, and much flattened. They are fairly primitive[1] animals; yet they are definitely a higher type of animal than the cœlenterates. Unlike both the cœlenterates and the even simpler sponges, the bodies of which consist of only two layers of cells, the flatworms have bodies made up of three layers of cells. Thus the flatworm is the most primitive animal having the three-layer plan of body development common to all the higher animals. All flatworms, moreover, are bilaterally symmetrical; that is, they can always be divided into similar right and left halves. This bodily arrangement is the same as that possessed by the more successful higher animals. Among the flatworms, too, are the simplest crawling Metazoa. Flatworms have fairly well-developed reproductive,[2] excretory,[3] muscular, and nervous systems, a fact which indicates a much higher degree of division of labor among the cells and tissues of the body than is found in the simpler animals already discussed.

Fresh-water flatworms, like those of Fig. 103, can be found on the undersides of stones or in the mud at the bottom of streams

[1] *Primitive* (prim'i tiv): showing an earlier or a simpler stage of development.
[2] *Reproductive* (re pro duk'tiv): having to do with reproduction.
[3] *Excretory* (ex'kre to ry): having to do with excretion.

and ponds in almost any part of the earth. The life processes of one of these simple flatworms will be discussed in several later sections of this book.

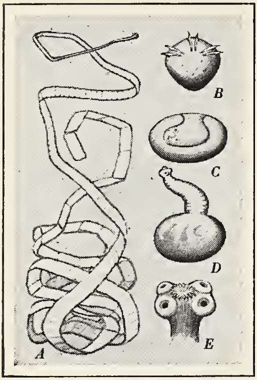


Fig. 104. What may one do to prevent becoming a host to this parasite (*Tænia saginata*)?

Flatworms interest us chiefly because many of them live as parasites in the bodies of man and other animals. There is probably not a single group of higher animals that escapes being made a host by some of these worms. Several are intestinal parasites, occurring in the dog, the pig, fish, man, sheep, and many other animals. Others may live in the muscles of the pig, the cow, and man. Still others may be found in such organs as the liver. A few of these forms will be discussed here both because they are important economically and because they have such unusual and complicated life histories.

***Tapeworms.** The tapeworms are among the best-known flatworms. Most of these parasites require two different hosts in order to survive. They go through a different stage of development in each host in turn (Fig. 104). There are many species, which live in the intestines of animals. Fifteen or more species are known to infest[1] man, but only four varieties are especially important as human parasites. These are the beef tapeworm, the pork tapeworm, the double-pored cat or dog tapeworm, and the broad fish tapeworm of man. Tapeworms are made up of parts that look like segments, which number from three to several thousand, depending upon the species. The adult form of the most familiar tapeworm is a ribbonlike worm (Fig. 104, *A*). It is firmly attached by sucking disks or by hooks on the head (Fig. 104, *E*) to the wall of the small intestine of its host. The body floats free in the intestine, and is surrounded on all sides by digested food, which it takes into every part through the body wall. So depend-

[1] *Infest* (in fest′): to be present in such large numbers as to be annoying or dangerous.

ent has the tapeworm become during its long process of adaptation[1] that it has lost all traces of a digestive system of its own. Moreover, it depends on its host for shelter and warmth, as well as for food.

The tapeworm undergoes a complete metamorphosis in developing from newly hatched young to the adult stage. The eggs get into the first host, such as a cow, a pig, or a fish, along with food or water. As soon as it hatches from the egg, the young tapeworm (Fig. 104, *B*) bores into the muscles of its host. Here it grows and develops through two stages (Fig. 104, *C* and *D*). It can never develop into the adult stage in this first host. But if the meat containing the young tapeworm (Fig. 104, *D*) is eaten without being well cooked, the worm continues its development to the adult stage in the intestine of man. Here as an adult it may sometimes attain a length of more than thirty feet. It grows by adding new sections just back of the so-called head. This process keeps pushing the older, wider parts of the body farther and farther back. Every section contains both male and female reproductive organs. Enormous numbers of eggs are produced by these prolific[2] animals; indeed, nearly the entire space within a segment is taken up by the egg masses. When the eggs are ripe, the segments break off, usually in chains, and pass out of the body with the feces, or wastes from the food canal. If a suitable host happens later to swallow these eggs with its food, the life story goes on in the same way (Fig. 105). But if no suitable host comes along, the young tapeworms in the eggs soon die. Such parasites by producing thousands of young survive, even though there is so slight a chance that the eggs will be swallowed by a suitable host or that the partly developed young in the flesh of the first host will be eaten by a suitable second host in which the adult worm may develop.

A tapeworm living in the intestine of man or of any other animal interferes with digestion and may absorb so much food that the health of the host becomes affected.

[1] *Adapt* (a dapt'): to adjust or accommodate to the environment. *Adaptation* (ad ap ta'shun): act or process of adapting, state of being adapted; a structure which is especially suitable to its environment.

[2] *Prolific* (pro lif'ik): producing many young.

Under certain conditions the pig tapeworm uses man as the intermediate host. If its microscopic eggs or newly hatched

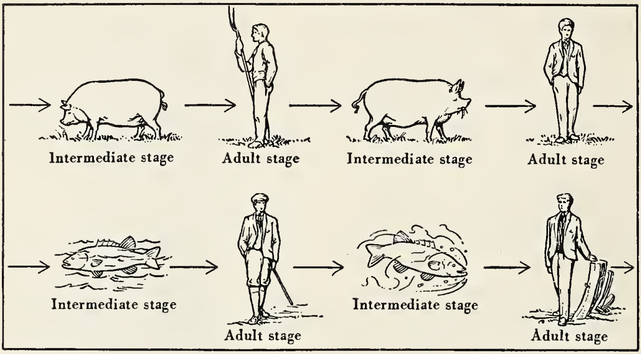


Fig. 105. Tapeworms require two hosts. With the help of the text, can you explain the metamorphosis of the tapeworm?

young find their way into the mouth from dirty hands or unclean food, the young worm may be carried to almost any part of the human body, the muscles, lungs, eyes, brain, or heart, causing more or less serious injury. The eggs of several species of tapeworm, including the pig tapeworm, can be carried to man by house flies which deposit the eggs on food.

Liver fluke. The liver fluke has a complex life history. During its metamorphosis it has five different forms besides the egg. This worm is a flatworm which as an adult lives in the bile ducts of the sheep, occasionally of the cow, the pig, and rarely of man (Fig. 106). It may cause the death of its host. Each adult worm (Fig. 106, *a, f*) may lay as many as half a million eggs. These do not hatch in the sheep, but pass with the bile from the liver into the intestine, and then out of the body with the feces. If these eggs fall into water or are carried to water before they die, they hatch into free-swimming larvæ (Fig. 106, *b*). These swim about until they find a certain species of water snail; if they are not successful in finding this snail, they die in a few hours. If a larva finds a snail, it bores its way into the snail's tissues and in about

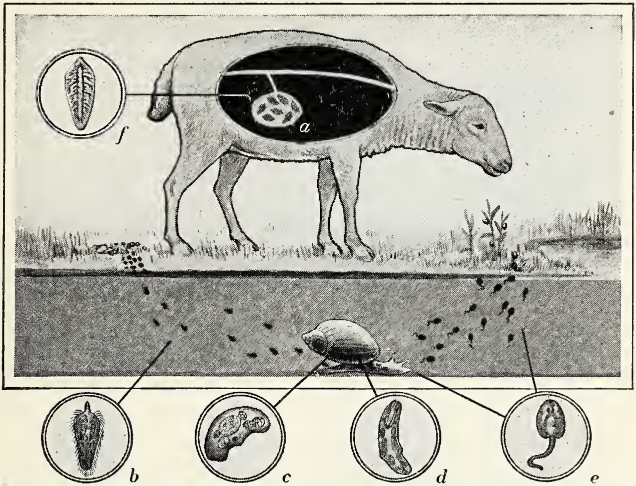


FIG. 106. The liver fluke requires two hosts. With the help of the text, can you explain the metamorphosis of the liver fluke? Why is its metamorphosis said to be a complete metamorphosis?

two weeks changes its form again (Fig. 106, *c*). Soon it begins to reproduce rapidly, forming many small larvæ of a still different form (Fig. 106, *d*). These in turn produce one or more generations of young like themselves. Eventually these produce still another form of tailed larvæ unlike any of the preceding forms (Fig. 106, *e*). These tailed larvæ leave the snail's body. They swim around for a while, and then form cysts, which protect them for a short time. If a sheep or other possible host, such as a deer or a rabbit, drinks the water containing them or eats the grass on which they are encysted,[1] their development continues in this second host. If they do not happen to be taken into another host's body, they die. But if they do get into the body of a second host, the cyst is dissolved by the action of the digestive juices, and the larva makes its way to the liver, where it develops into an adult in about six months (Fig. 106, *f*).

[1] *Encyst* (en sist'): to inclose or become inclosed in a cyst, or capsule.

Self-test on Problem X–D. **1.** A true worm has *no* metamorphosis.

2. The flatworm marks a higher stage of development than the sponges or the cœlenterates because it has a *two*-layered body.

3. The three phyla which include the true worms are the --(?)--, the --(?)--, and the --(?)--.

4. The most important flatworms are *saprophytes.*

5. The tapeworm takes in its food by the process of *photosynthesis.*

6. One need never fear becoming the host of a tapeworm if the meat one eats is always *well cooked.*

7. A *flatworm* which sometimes infests sheep is the liver fluke.

Problem X–E · What are Some Adaptations of the Roundworms (Phylum Nemathelminthes) which Make them Successful Animals?

Roundworms more complex than flatworms. The roundworms are somewhat more advanced in the scale of life than the flatworms. They have a food tube, or alimentary canal, which lies in a body cavity.

Some species of roundworm are marine, others live in fresh water, and still others live in the soil. With the roundworms as with the flatworms, however, the most important species are parasites of plants and animals. Perhaps the most formidable of these are the hookworm, the parasite that causes trichinosis (*Trichinella*), and a parasite of the intestines (*Ascaris*).

The hookworm. Hookworm disease is prevalent in most warm countries. It is caused by a little worm not more than a quarter to half an inch long which may live in the intestine of man. Scientists working with the Rockefeller Foundation have made a study of conditions all over the world, and they report that in some countries nearly all the people have become infested with this parasite. In southern China 65 per cent of the population are affected; in India as many as 95 per cent have the disease; and in southern United States the loss of human energy and even of human life is appalling (Fig. 107).

*The larvæ of this worm live in moist ground and get into the bodies of human beings by boring through the skin, usually of the

feet. In countries where the disease is prevalent the people go barefoot much of the time. The larvæ are taken up by the blood stream at the point where they enter the skin, and are carried to the heart. From there they follow the blood stream to the lungs, through which they bore. From the lungs the worms may pass up the windpipe (trachea) to the throat. They are then swallowed and finally reach the intestine. The parasite attaches itself to the wall of the intestine and sucks the blood of its host. At the same time it pours into the wound a poison which keeps the blood from clotting. Therefore, even after the worm has left the spot, blood may continue to flow from the wound. The constant loss of blood weakens the host. Sometimes people of the South who are accused of being lazy are really ill from attacks of this parasite. The victim is also subject to tuberculosis because of injury to the lung tissue, and because of the loss of blood and consequently of the food which the blood contains and which is needed to nourish the body.

International Sanitary Commission

Fig. 107. The boy at the left is infected with the hookworm parasite; the other boy is not. Both are eighteen years old. State several ways in which the study of biology aids in fighting this disease

The eggs of the hookworm pass out of the body with the feces, and hatch into larvæ in the moist earth, where they are ready to attack a new host. When these facts are known, control is easy. If all human wastes are disposed of in such a way as to prevent pollution[1] of the soil, the disease can be stamped out readily. Sanitary toilets and the wearing of shoes are effective aids in eliminating the danger from hookworm.

[1] *Pollution* (pol u′shun): the act of making dangerously unclean.

***Trichinella* and *Ascaris*.** Like many other parasitic worms, the trichinosis parasite must pass part of its life in each of two hosts. The first part of its life is passed in the pig, where it rests encysted in the muscles. If this meat is eaten by man before it has been thoroughly cooked, the digestive juices dissolve the cyst, and the worm is set free in the intestine. It reproduces there, depositing as many as ten thousand young. These find their way by means of the blood stream to the muscles. They bore through the tissues and produce swelling and painful inflammation (Fig. 108). The muscles most liable to be infected are those which have a plentiful supply of blood, as the muscles of the thorax and diaphragm.

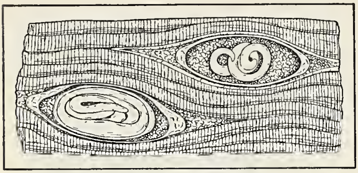


FIG. 108. A trichinosis parasite in human muscle. How may one guard against becoming infected with this dangerous parasite? About fifteen hundred species of roundworms are known

*The prevention of the disease lies in thoroughly cooking all pork. This is important since there is no government inspection for the trichinosis parasite.

Some of the roundworm parasites (*Ascaris*) live in the lower intestines of children, dogs, pigs, and probably many other animals. Except that these enter through the mouth instead of through the skin, they have a life history similar to that of the hookworm. Many cases of pneumonia in children are caused by these parasites.

Self-test on Problem X–E. 1. Roundworms mark a higher stage of development than the flatworms because (1) they are parasites; (2) some species live in the ocean; (3) they have an alimentary canal in a body cavity; (4) the adults are always wormlike; (5) they are in general much smaller than flatworms.

2. One may become infested with the *hookworm* parasite by going barefoot.

3. Roundworms are parasites in *few* animals besides man.

4. Roundworms cause *small loss* of life.

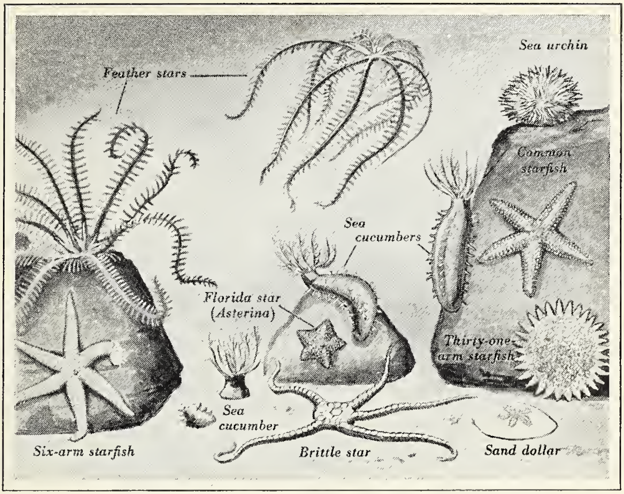
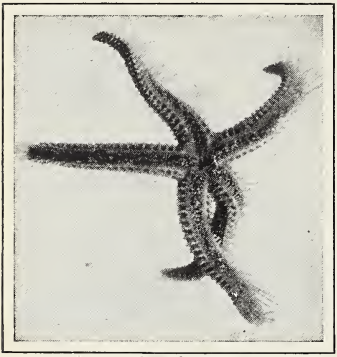


FIG. 109. The echinoderms are not here represented in their correct relative sizes. Also, one would not find so many kinds together in one place. There are about four thousand species of echinoderms. What is meant by the statement "Echinoderms are littoral animals"? (See dictionary)

Problem X–F · Why are the Echinoderms (Phylum Echinodermata) Able to Compete successfully for Energy?

Spiny-skinned animals that live in the sea. If you were to explore the pools around rocks on the ocean beach at low tide, you might find something which resembled a small round black or purple cactus. This is a sea urchin. Near by on the rocks you might see purple or orange starfish and on the beach gray sand dollars which had been washed up by the tide. Most of these sand dollars would probably already have been broken by sea gulls preying upon the animals inside the shells. The sea urchin, starfish, and sand dollar are members of the phylum Echinodermata, or spiny skins. They are given this name because all have exoskeletons made up of bony and often spiny plates.

With almost no exception the echinoderms are all marine forms, living mostly in tide water, or the shallow water along the ocean shore (Fig. 109). All have radially symmetrical bodies. Most of the echinoderms have five arms, or rays. Occasional starfish, however, have six or seven, and some basket stars and serpent stars have several times as many. Most species of echinoderms can move about slowly. A few stalked forms are attached to rocks or other supports.



General Biological Supply House

FIG. 110. A starfish seen through glass, upon which it is walking. Can you describe how it walks?

The starfish, a typical echinoderm. Starfish are found on the ocean shores in all parts of the world. The living animal is flexible and moves about readily, walking on the tips of the bent-over arms or swimming by moving the arms back and forth. Like its near relatives, the sea urchins, brittle stars, sea cucumbers, and others, it also possesses another very peculiar means of locomotion, its tube feet (Fig. 110). These are small fingerlike structures which line the edges on the under (ventral) side of each arm. When they are filled with water, which is taken in through a sievelike plate on the upper surface, they extend from the body until they touch some object. Then some of the water is withdrawn from each tube, forming a partial vacuum inside. The suckerlike tips of the tube feet stick to the support, because the water pressure or air pressure (if the starfish is uncovered) pushes the tube feet against the surface. Thus the starfish can cling to a vertical wall, and by holding fast with some of its arms while advancing the rest, it can move slowly about over the rocks.

Importance of echinoderms. The echinoderms are relatively unimportant to man. Starfish interfere with the oyster industry by feeding upon the oysters. Sea cucumbers, dried and sold under

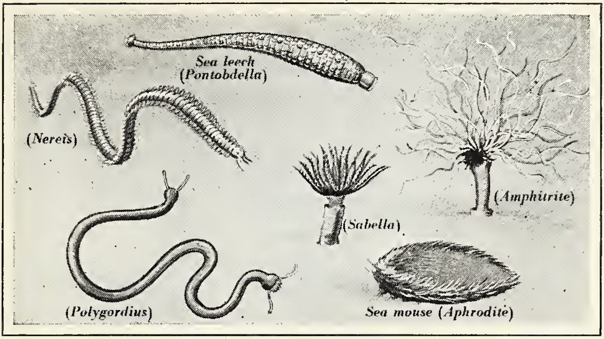


FIG. 111. Can you name a common annelid not shown in this group of marine annelids? There are about four thousand species of annelids

the name of "trepang" or "bêche de mer," are commonly used for food in certain parts of China and in the south-Pacific islands.

Self-test on Problem X–F. 1. *Few* echinoderms live in salt water.

2. Echinoderms are of *great* economic importance.

3. *Starfish* are used as food in some parts of the world.

4. Select from the following list of animals those which belong to the same phylum: (1) starfish; (2) *Pandorina*; (3) sand dollar; (4) sponge; (5) jellyfish; (6) sea cucumber; (7) basket star; (8) liver fluke; (9) pin-worm.

Problem X–G · What are Some Adaptations of the Segmented Worms (Phylum Annelida) which Make them Able to Compete successfully for Energy?

Annelids are segmented worms. The third phylum of worms, the annelids, includes some four thousand species. Many of these are burrowing earthworms and sandworms (Fig. 111) of various kinds. Another group is made up of leeches of several sorts, some of which live in the ocean, while others are familiar pests in our streams and lakes. Still other annelids are found in or near the water of streams and seas. All members of this phylum have bodies that are clearly made up of segments, or ringlike sec-

tions. This segmented structure marks an important advance over the structures of the simpler phyla already discussed, since it is characteristic of the two most successful groups of higher animals, the arthropods and the chordates, which will be described later.

Unlike other groups of worms that we have studied, few of the annelids are parasitic. The leeches are temporary parasites; that is, they attach themselves to a frog, a fish, or a man only long enough to suck a meal of blood.

***The earthworm, the commonest annelid.** The earthworm is abundant almost everywhere that the soil is moist, loose, and rich in organic matter. Its body is long, slender, and cylindrical — well fitted for burrowing through the ground.

Experiment 42.[1] How does an earthworm move? Watch a live worm crawling. How can you distinguish the head end? Does the worm always proceed head foremost? How long is the worm when at rest? How long is it when it is stretched out as far as possible? How many small sections, or segments, make up the body? Count the number of segments in other specimens. Is the number the same for all earthworms? Pick up the worm and rub one finger along the undersurface. Can you feel the stiff projecting hairs (setæ)? How many of these are there on each segment? Use a hand lens if you have one. What are these bristles used for?

Look closely at the dorsal (upper) surface of a live earthworm. Can you see the movement of the blood in the dorsal blood vessel? Does it flow forward or backward?

Where is the mouth? Describe it.

Experiment 43. What is the internal structure of the earthworm (Fig. 112)? For this dissection use as large an earthworm as you can secure. You may use a preserved specimen, or you may kill a worm by putting some ether in the water around it. Stretch the worm out on a pinning pan, or on a piece of board, such as a shingle. With fine-pointed scissors cut through the body wall along the back of the animal, beginning at about halfway back and continuing forward to the head. Pin the body wall back by thrusting pins through it into the wax or board.

[1] To the Teacher. Experiments 42 and 43 are placed at this point in the text in order that the earthworm may be studied as a complete animal. Various structures and functions of the earthworm are studied in more detail at many other points in this book.

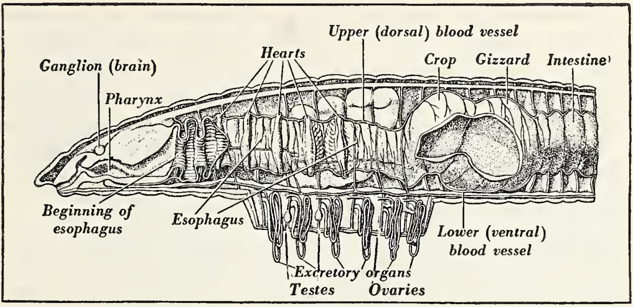


Fig. 112. The internal structure of the earthworm. An organism having many similar structures is said to be a primitive organism. Can you explain this statement?

Note the fine partitions which hold the body wall in place. Do they bear any relation to the segments? The space between the body wall and the internal organs is the body cavity. Trace the digestive system, which consists of mouth, pharynx, esophagus, crop, gizzard, and intestine. Is the intestine coiled, or is it a straight tube? Above the digestive tract find a blood vessel which extends the length of the animal. There is a similar blood vessel below the digestive tract as well. Many smaller vessels connect these two. Near the head end look for the five pairs of hearts, which are merely enlarged connecting vessels. Now remove a portion of the intestine and examine the floor of the body cavity for the nerve cord. This nerve cord is enlarged in each segment to form a ganglion. The brain is above the pharynx. Can you find it? (See also Fig. 191, p. 288.)

The earthworm moves by stretching out the anterior, or head, end and then drawing the rest of the body forward. This movement is accomplished by two sets of muscles, one set (circular muscles) running around the body and the other (longitudinal muscles) running lengthwise. If you can imagine two sets of rubber bands in such positions, you will understand the arrangement of these muscles. When the circular muscles in the anterior part contract, the head end is stretched forward. Then the longitudinal muscles shorten, and the rest of the body is pulled forward. To keep the anterior part of the body from being pulled back, the worm has a number of bristles (setæ) which point backward and act like braces to hold it in position.

***Importance of annelids.** With the exception of the earthworm the annelids are of little economic importance. The earthworm, however, enriches the soil for agriculture with its casts, or feces. Charles Darwin, a noted English biologist, estimated that the earthworms in an acre of ground would in twenty years transfer to the top of the ground a layer of rich soil three inches deep. The numerous burrows, moreover, admit to the soil air containing oxygen, which is needed by plant roots.

Self-test on Problem X–G. **1.** The annelids have *external* skeletons.

2. The annelids mark a higher stage of development than the flatworms, the roundworms, or the echinoderms because they have bodies made up of __(?)__.

3. The most familiar annelid is the __(?)__.

4. Select from the following list of animals those which belong in the same phylum: (1) leech; (2) sea cucumber; (3) *Hydra*; (4) earthworm; (5) sandworm; (6) tapeworm; (7) trichinosis parasite; (8) *Volvox*; (9) sponge.

Problem X–H · What are Some Adaptations which Make the Mollusks (Phylum Mollusca) Successful Organisms?

Mollusks are both land and water animals. You have probably seen in a stream bottom shallow grooves as if made by dragging a twig over the surface of the mud. If you follow one of these tracks, you will find a water snail or perhaps a fresh-water mussel or clam (Fig. 113, *A*). These animals are mollusks.

*Mollusks are found all over the world. Some, as we have seen, live in the ocean (Fig. 113, *B*). Some of these marine forms — for example, sea mussels, abalones, oysters, and periwinkles — cling to the rocks and other objects along the shores. Clams burrow in the sand of the sea beaches or the sand-and-mud flats of the bays. Other mollusks, like the squid and the octopus, are free swimmers and are found not only in the shallow water along the ocean shore but also in deep water. Others, like the common snails and garden slugs, live on land.

*All the mollusks have soft bodies. Most of the members of this group, however, are inclosed in a shell which represents the highest development of this type of protective covering.

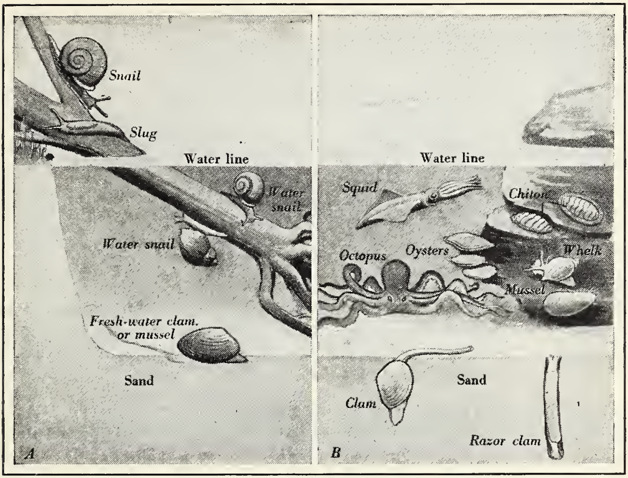


FIG. 113. *A*, fresh-water mollusks; *B*, marine mollusks. There are more than six thousand species of mollusks. How many mollusks can you name of which man is a dangerous enemy?

Every mollusk has an organ called a foot. The snails use this foot for locomotion. The burrowing mollusks use the foot for digging into mud, wood, and even, in the case of the rock oyster, into rock. The swimming mollusks use both the foot (which in the case of the octopus consists of eight arms and in the case of the squid and the cuttlefish of ten) and a funnel for seizing their prey. Most of the mollusks are either male or female, though a few have both kinds of sex organs in the same body.

Those mollusks which are inclosed in shells are usually protected very completely. A clam can draw its body in and close the shell against attackers; a snail can withdraw into its shell when it is molested. For this protection, however, these mollusks have had to sacrifice speed. "Slow as a snail" is a familiar saying. Perhaps you have watched a fresh-water mussel or fresh-water clam thrust its foot out into the sand and slowly draw its body along. It has no need to hurry. The water brings it food to eat and oxygen to breathe, and it is so well protected that most

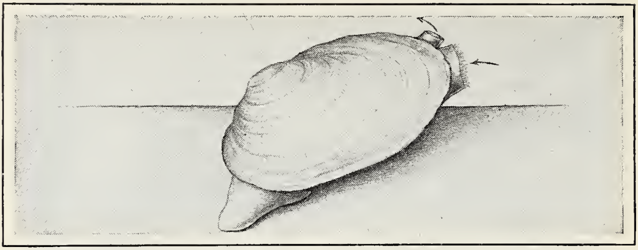


FIG. 114. The clam does not shed its shell, but grows by adding layers around the edges. Which is the oldest part of the shell? The goeduck clam of Puget Sound sometimes weighs six pounds, and its length from the end of its stretched-out siphon to the other end of its shell may be more than three feet. What survival value may this long siphon have?

of its enemies are not likely to trouble it. The free-swimming mollusks do not have the protection of external shells, and hence they must be able to move rapidly if they are to survive. The octopus, the squid, and the cuttlefish may escape from their enemies by swimming quickly away. A strong jet of water directed either forward or backward through the funnel propels the animal in the direction desired, while it steers its course with its arms held together.

Have you ever had the experience, on picking up a clam, of having a stream of water squirted out as the shell closed? If you should examine the animal closely, you would discover that the water came from the tube at the posterior, or rear, end of the shell. There are really two such tubes joined together, one through which the water enters, carrying food and oxygen, and the other through which it leaves, carrying wastes (Fig. 114).

Life history of the mussel. The young of most mollusks are free-swimming larvæ, not at all like their parents. The life history of the fresh-water mussel will serve as an example for this phylum. The female carries the newly hatched young in her gills. While still very young they develop shells and drop off their mother's gills into the water. The shells, which are armed with sharp-hooked teeth, open and close continuously (Fig. 115). When a fish swims by and touches the tiny mussel, the shells clamp to-

gether on some soft part usually of the fish's gills or fins. After the young mussel has become attached, the tissues of the fish's body grow around it, forming a cyst. So for several weeks it remains here. During this time it develops most of the structures of an adult mussel. Then the cyst breaks, and the young mussel drops to the bottom of the stream or lake to become an independent animal.

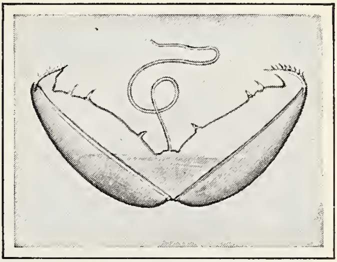


FIG. 115. Is the mussel larva a parasite? Explain

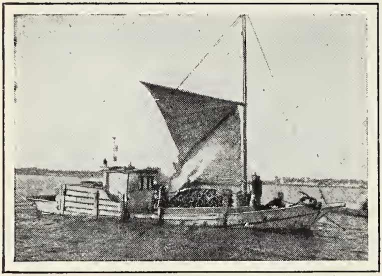
Every mussel has some particular species of fish to which it will attach itself for this stage. No other fish will do. If the right kind of fish does not happen to swim by at just the right time, the mussel dies.

The United States Bureau of Fisheries makes use of this knowledge of the life history of the mussel to stock again rivers and lakes from which the mussels have been nearly exterminated. The right kind of fish are put into tanks where there are many of the tiny mussel larvæ, ready to attach themselves to a host. Then the fish are returned to the rivers and in time furnish a new supply of mussels to those waters.

Value of mollusks to man. Oysters are among the most valuable of all sea products (Fig. 116). In the United States alone the cost of oysters sold for food runs into millions of dollars a year. In the more thickly populated parts of the world the natural supply of oysters long ago ceased to meet the demand, and various methods of artificial propagation have been resorted to. There are many "oyster farms" in Chesapeake Bay and elsewhere along the Atlantic and Pacific coasts.

Many mollusks other than the oyster are used for food. Marine clams (Fig. 113, *B*), scallops, and abalones are widely used. Periwinkles and certain species of land snails are eaten by European peoples. Squids are eaten in China and in some parts of Europe and occasionally are found under the name *ink fish* in our own markets. Squids are favorite bait for cod and for other large fish.

The teredo, or shipworm, which is not a worm at all but a mollusk with two shells like the oyster, does great damage to wooden ships and the wooden pilings of wharves. It sometimes burrows in these to a depth of two feet and often honeycombs the pilings so as to destroy the foundations of a wharf in a few years.



Anthony V. Ragusin

Fig. 116. An oyster lugger at Biloxi, Mississippi. Special Report: Discuss the oyster industries of the Gulf of Mexico, the Chesapeake Bay region, and the Pacific coast. (Consult bulletins from the United States Bureau of Fisheries)

Most of the buttons that we use today are made from the shells of clams and mussels. Until very recent times there was an abundant supply of fresh-water mussels in the rivers of the Mississippi Valley. But the factories that were established for the manufacture of buttons soon overfished the rivers. Through a knowledge of the life history of the mussels, the waters are again being stocked. Intelligent use of the adult mussels, so that fewer are destroyed, will provide for the continuance of this profitable industry.

Several mollusks furnish mother-of-pearl, the beautiful iridescent lining of the shell. The abalone, epecially, supplies particularly fine material used in inlay work. Pearls are formed of this same material when it is secreted around some foreign object, such as a parasitic worm or a grain of sand, lodged between the membrane which lines the shell and the shell itself. In Japan and China small images of Buddha are placed in pearl oysters. When after a year or so these are removed, they are found to be coated with pearl and are sold as religious images. The most valuable pearls are formed by the pearl oyster of tropic seas. But true pearls, some of them of rare beauty and valued at many thousands of dollars, have been found in mussels taken from the rivers and streams of the Mississippi Valley and of many other sections of the United States.

Self-test on Problem X–H. **1.** *All* mollusks live in the ocean or in fresh water.

2. The mollusks mark the highest development of body protection by means of *bones.*

3. *All* mollusks have shells on the outsides of their bodies or shells into which they can draw their bodies.

4. The life history of the *mussel* illustrates complete metamorphosis.

5. Name four edible mollusks.

6. Which animals of the following list are mollusks: (1) shipworm; (2) trichinosis parasite; (3) oyster; (4) clam; (5) mussel; (6) *Paramecium*; (7) sponge; (8) sand dollar; (9) jellyfish; (10) abalone; (11) snail?

Self-test on Biological Principles. **1.** Certain species of sponges grow only on the legs or backs of certain crabs. The sponge benefits the crab by protecting and to some extent concealing it from enemies. The crab benefits the sponge by carrying it about, thus promoting freer oxygenation, that is, transfer of oxygen from the water to its cells. What principle of biology developed in an earlier chapter does this partnership illustrate?

2. In 1899 and 1900 the octopuses became so numerous in the English Channel, probably because of a succession of unusually mild winters and warm summers, as almost to ruin the crab and lobster fishing industries. How does this incident relate to the balance of nature?

3. While the oyster may lay nine million or more eggs in a season, some mollusks lay from twenty to a hundred, and one species as few as fifteen. The eggs of some species hatch in the form of adult mollusks, and the young of one species hatch in the body of the female. Why do not the latter species need to produce so many eggs as the oyster?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** How might man exterminate the liver fluke? What benefits may result from the work of biologists in discovering all stages of the life history of the liver fluke?

2. Not long ago four members of an Italian family in one of our great cities died of trichinosis which they had contracted through eating half-cooked pork sausage. Immediately the price of pork fell because many people were afraid to buy it. Was this fear justified? Explain.

3. How does a temporary parasite like the leech differ from a true parasite like the hookworm? from an animal of prey?

4. Can you name the phylum to which each of these organisms belongs: octopus, sponge, amœba, vorticella, coral, clam, tapeworm, hookworm, sandworm, snail?

5. Which phyla do you know to contain parasitic species?

Exercise on Scientific Method. 1. Planning Experiments to Find Out whether Certain Conclusions are Sound. Have you ever heard people say that worms are rained down? This conclusion is based upon the observation that earthworms are usually found on the sidewalk and in puddles after a heavy rain. How would you proceed to find out whether the worms actually fall with the rain? After you have reached definite conclusions from your experiments, can you explain why the worms are in the puddles?

2. Making Inferences. Considering the habitat of the tapeworm, would you infer that it had or had not a skeleton? Check the accuracy of your inference by consulting a college zoology or an encylopedia.

3. Inventing Hypotheses. Can you invent a probable explanation of how the octopus uses the water pressure of the ocean in holding its prey?

Project 10. To secure and observe flatworms. See whether you can find flatworms about half an inch long in near-by creeks and ponds. Put them in shallow dishes of water. Try to feed them with tiny pieces of liver. Can you find the two eyespots near the head end? What other organs can you discover? Consult a zoology text for further information.

Project 11. To find out whether "horsehair snakes" really develop from a horsehair. This roundworm, which looks like a horsehair, is often found in moist spots around springs and streams and sometimes around horse troughs. It also lives as a parasite in the body of the grasshopper. Put a horsehair in water and let it stand for a week or so. Does it develop into a living worm, as many people believe it will if left in water? Look up the life history of the horsehair snake in an advanced zoology textbook.

Project 12. To grow snails through the complete life cycle. Collect living land snails from a wooded region or water snails from a pond or creek, or secure land or water snails from a biological supply house. For the land snails put a layer of wet earth in the bottom of a large jar, such as a battery jar. Put in the snails along with a leaf of lettuce for food. For the water snails fill a large jar with water. Put in the snails along with some water weed. Observe the snails from day to day. Make complete notes of all your observations.

Special Reports. 1. What is the Great Barrier Reef of Australia (Fig. 8, p. 18)? What are some of the islands that are formed largely

by coral? What is precious coral, and where is it found? In what ways might coral reefs and coral islands be of considerable importance to man? (Consult an encyclopedia or a college textbook in physiography or zoology.)

2. What has the United States government done to stamp out hookworm disease? (Consult bulletins secured from the United States Department of Agriculture.)

3. Describe the important characteristics, life habits, and the economic importance of the gapeworm, which is a parasite in chickens. (Consult a textbook on agriculture or secure from the United States Department of Agriculture bulletins on farm parasites.)

4. To what extent could Victor Hugo's description of Gilliat's battle with the octopus in *The Toilers of the Sea* be true? (Consult an encyclopedia for facts about the octopus.)

5. Describe the chambered nautilus.

Chapter XI · The Insects and their Relatives

Questions this Chapter Answers

What are some respects in which all animals of this group are alike?

What are some characteristics of the members of this group?

What are some of the characteristics and adaptations of the crayfish which make it a successful animal?

Of what importance is the crayfish?

How are insects classified?

What are some of the characteristics and adaptations of insects?

What are typical examples of incomplete and of complete metamorphosis in insects?

In what respects are insects well fitted for survival?

Problem XI–A · What are Some Adaptations of the Arthropods (Phylum Arthropoda) which Make them Successful Animals?

Unlike in appearance; alike in fundamental structure. It may not seem at first thought that a butterfly is much like a flea or an ant; that the common house fly closely resembles the sea barnacle (Fig. 24, p. 42); that a spider is much like a scorpion; or that a crayfish is very similar to a centipede. Each of these animals is different from the other named with it in general appearance, in its habitat, in its means of locomotion, in its feeding habits, and in other respects. If, however, we compare the structures of all these animals, we find them similar in important respects. Each has an exoskeleton which covers it completely like a suit of armor (Fig. 117); and just as a suit of armor must be jointed in order to permit movement of the various parts of the body, so must the exoskeleton have joints. The body of the animal inside the exoskeleton is therefore in segments, or conspicuous parts. Attached to each segment are usually one or more pairs of appendages,[1] such as legs. These appendages, like the body, are jointed.

[1] *Appendage* (a pen'daj): a jointed organ attached to the body.

*All these armored and jointed animals, however different they may be in minor respects, and wherever they may live, are grouped into one phylum because of their fundamental likenesses in structure. This phylum is known as Arthropoda.

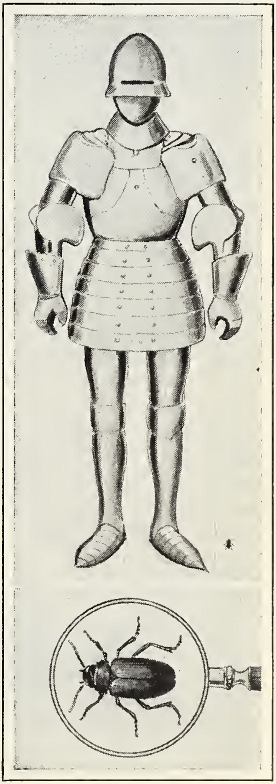


Fig. 117. Artificially and naturally armored organisms. Compare the advantages and disadvantages resulting from wearing armor

The classes of arthropods. The arthropods include over a million species, a number probably greater than that of the species in all the other phyla of the animal kingdom combined. These animals are common in all but the coldest parts of the world. Different species are found in or upon the ground, in trees, in fresh water, and in the ocean. The arthropods are divided usually into five classes (Fig. 118), of which the four most important will be considered here.

1. Crustacea, common examples of which are the crabs, crayfish, and lobsters, are aquatic animals which breathe by means of gills. The body is divided into two parts, the head-thorax and the abdomen. On the head are two pairs of antennæ, and attached to the thorax are the legs. The number of legs varies from five pairs in the crayfish and the crab to as many as thirty pairs in some of the very small crustaceans found in our ponds and pools. Many of the larger members of this group, such as the lobster, crab, crayfish, shrimp, and prawn, are used for food by man. These and many smaller crustaceans (Fig. 119) form the chief food of many fish, especially of young fish.

One important member of this group, the crayfish, will be considered more in detail later in this chapter and also at other places in this book.

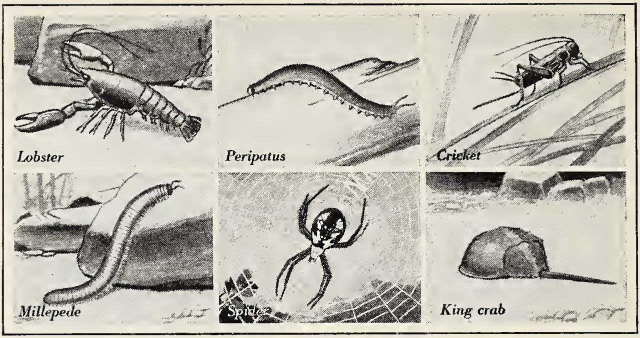


Fig. 118. Examples of the classes of arthropods. Special Report: Where is *Peripatus* found? How does this animal illustrate "discontinuous distribution"? What are its characteristics? (Consult a college textbook of zoology or entomology.) The king crab is often classed as an arachnid. It is the last remaining representative of a class that was abundant a million years ago

2. Insecta is the name of the class which includes such animals as grasshoppers, flies, butterflies, beetles, ants, and fleas. All these have three pairs of legs, never more and never fewer. In the adult stage they usually have wings, though the young, or larvæ, may be wormlike. They breathe by a system of air tubes (tracheæ). There is one pair of antennæ.

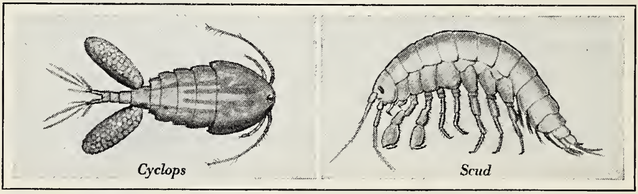
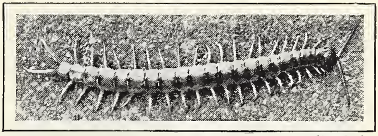


Fig. 119. Are these two tiny fresh-water crustaceans indirectly of value to man? Explain

The body is divided into three distinct parts: head, thorax, and abdomen. Insects are so important to man that they will be discussed at frequent points in later chapters.

3. Arachnida include the spiders, harvestmen, mites, ticks, and scorpions. The head and thorax are united, as in the Crustacea, giving them a very different appearance from the insects. Spiders feed on insects and

so are beneficial to man. Contrary to popular opinion very few spiders are poisonous. Of the poisonous ones the tarantula, a large hairy spider which is found in southwestern United States, is best known. But, though its bite is painful, it is seldom fatal. The scorpion is able to inflict a painful wound and its sting is slightly poisonous.



Cornelia Clarke

Fig. 120. Which end of the centipede is its head? How can you tell?

Many arachnids are of importance to man because they live as parasites on domestic animals and may carry certain diseases from one animal to another.

4. Myriapoda are the "thousand legged" worms, such as the centipedes and the millepedes. The body of a centipede consists of from fifteen to over one hundred fifty segments, each of which bears one pair of legs (Fig. 120). Centipedes can move very rapidly. We may find them under the bark of old logs or under stones. One species is sometimes found in our cellars. They are insect-eaters and so are beneficial. Some species, living in southern and southwestern United States are poisonous.

The millepedes are black wormlike animals with two pairs of rather short legs on each segment. They move slowly, and when disturbed may roll themselves up into a ball. In spite of their rather formidable appearance they are harmless to man. Millepedes feed on vegetation entirely.

Self-test on Problem XI–A. 1. As with the annelids, the bodies of the arthropods are made up of __(?)__.

2. The appendages of arthropods are attached to the *abdomen* in pairs.

3. *Few phyla* contain more species than the phylum which contains the arthropods.

4. Name the four most familiar classes of arthropods and give two common examples of animals in each of these classes.

5. *Some* millepedes inflict poisonous bites.

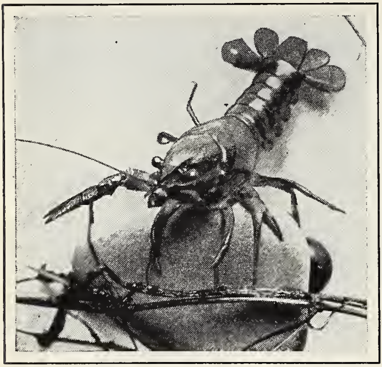
6. *Most* spiders inflict poisonous bites.

7. *All* insects have *eight* legs.

Problem XI–B · What are Some Adaptations which Make the Crayfish a Successful Animal?

Habitat. The crayfish (Fig. 121), sometimes called crawfish, is abundant in most fresh-water lakes, ponds, and streams of North America and Europe. Although it is an aquatic arthropod, it can

live on land for short periods. Some species are often found on stream banks or even at some distance from water. During the day the crayfish hides under rocks or logs or in burrows which it makes in the mud or clay of the banks or stream bottoms (Fig. 122). Only the head extends out of the place of concealment, with the antennæ and the eyestalks constantly moving to detect any approaching object.



Cornelia Clarke

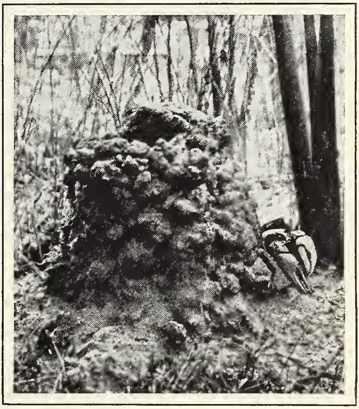
FIG. 121. What indicates that this crayfish is ready to make a quick escape? How will it make its escape?

Experiment 44.[1] What are some of the most important characteristics of the crayfish? (Answer the questions in complete sentences or by means of labeled diagrams.)

1. How does the crayfish move about? Place the live crayfish on the table. How does it move? Does it use all its legs? Can it move sideways? backwards? How does it seem to know where it is going? Do you find any evidence that it is using its eyes? its antennæ? Put it in a vessel of water. How does it move now? What part of its body does it use to produce this movement? Describe. Which of these methods of locomotion would be more useful in finding food? in escaping from enemies? Which is the more rapid method of locomotion?
2. In what respects is the crayfish like the insects? Compare the crayfish with any convenient insect, such as a beetle or a grasshopper. What resemblances do you find between the two? What principal differences? How many body regions does each have? Is the head of each movable? Is the abdomen of each segmented? (The crayfish abdomen looks like a tail.) Does the crayfish have more or fewer appendages than the insect? How many legs does each have? What differences can you see in the different pairs of legs of the insect? of the crayfish? What is the use of each pair as far as you can observe?

[1] TO THE TEACHER. This experiment is given here to acquaint the students with the crayfish as a complete animal. Separate discussions of the structures and functions of various organs will appear at other points in the book.

How many eyes does the crayfish have? Are they like the eyes of an insect? Are they compound? You will find one long pair and one shorter pair of antennæ on the crayfish. (The latter are two-parted, appearing at first to be two pairs.) Does the insect have similar antennæ? Are the antennæ segmented? Do they move readily? Where is the mouth of the crayfish? What movable parts can you see? Describe briefly. Try to get the animal to chew on a piece of paper or a pencil point to see how the mouth parts move. Describe.



Cornelia Clarke

FIG. 122. A crayfish chimney. Some species of crayfish dig long tunnels in clay banks. One opening is under water and the other is on land with a "chimney" of mud protecting it. How do you explain the fact that crayfish can live for some time out of water?

3. How is the crayfish protected? Hold the crayfish up in the air. How does it try to get away from you? What is the color of the living animal? Explain the survival value of this color. What are the advantages of having an exoskeleton such as the crayfish has? What are the disadvantages? List all the adaptations for protection. Examine one of the legs of a preserved specimen. How many joints do you find? What is the advantage of having so many joints? In what directions can the leg or its parts move? Squeeze the leg firmly between the fingers. Does it crush easily? Remove the hard covering to expose the muscles of the leg. Try to find where these muscles are attached.

4. How does the crayfish breathe? Hold the live crayfish, ventral (under) side up, in a pan of water. (The water should just cover the animal.) Put a drop of ink near the base of the posterior (rear) legs. Where does the ink reappear? Can you explain? Make a sketch to show the path of the water bearing the ink. Use a preserved specimen for these next observations. With scissors cut off the shell (carapace) on one side of the body. The region exposed is the gill chamber. Describe the gills. Cut off the middle leg close to the body, keeping the point of the scissors between the leg and the body. What relation

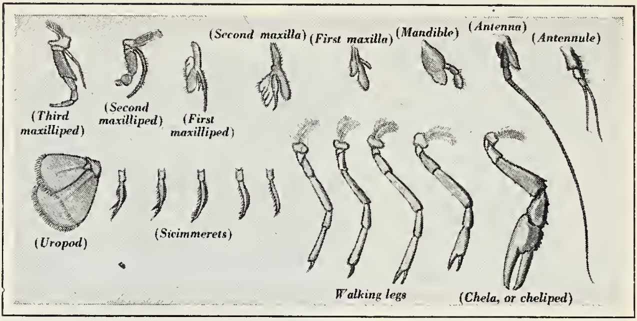


FIG. 123. The appendages of a crayfish. The last five in the top row are attached to the head; the first six in the second row to the abdomen; the remaining eight to the thorax. Can you locate all these on a living specimen?

do you discover between legs and gills? Put a gill in water. What adaptations for its function of taking in oxygen do you observe? Draw accurately a leg with gill attached. Make your drawing about twice the natural size.

5. What further facts can you learn of the body regions and appendages? *The head-thorax* (*cephalothorax*). What structures appear when the head is viewed from above? What is the shape of the head? Can the live crayfish move its eyes? Gently touch an eye with your pencil. It will not hurt the crayfish. Why? What happens? Examine the eyes of a preserved crayfish. Of what advantage is the jointed eyestalk? Draw the head region from above. Make your drawing twice the natural size or larger. Label carefully. Examine the mouth parts (Fig. 123). Get help from your teacher to remove the mouth parts. Sketch them and properly label your drawings. Ask to have your work approved before proceeding.

The abdomen. How many segments in the abdomen? Do all bear appendages? The first two segments in the male have long rigid appendages used in reproduction. Those segments in the female bear small structures similar to those on the next three segments. All are called *swimmerets.* Of what use are they? The sidepieces of the tail fin are really modified legs (uropods). Note that they are two-parted like the legs and jointed as the legs are. Are they attached to the last or to the next-to-last segment? The last abdominal segment (telson) is part of the tail fin. Draw the abdomen, both dorsal (upper) and ventral (under) views, and label all the parts of each drawing.

6. What are the characteristics of the internal structures? Remove the exoskeleton from the thorax region of a preserved specimen. Push the gills aside and carefully cut away the body wall. With the aid of Fig. 192 (p. 289) identify (1) the heart, (2) the stomach, (3) the intestine, and (4) the digestive gland (hepatopancreas). Where is the stomach with reference to the mouth? Cut the stomach open. What unusual structures do you find? Of what use are they? Now remove any of the organs mentioned above that may remain. On the floor of the body cavity you can see the white *ventral nerve cord.* Follow it forward to the *brain,* which lies between the eyes.

***Adaptations for protection.** The crayfish has several effective means of protection: (1) It has protective coloration, that is, its color so closely resembles that of the rocks and sand of the stream bottoms that it can be seen only with difficulty when it remains quiet. (2) Its habit of remaining in hiding during the day and of feeding usually at night protects it from such enemies as the wading birds. (3) Its exoskeleton protects it from some fish and turtles. (4) Its ability to swim rapidly affords it an effective means of escape. (5) Its large claws are formidable weapons for attack and defense.

Movement. On land the crayfish seems awkward, though it can move fairly rapidly. Its body seems too heavy for its legs. However, it can walk backward and sideways as well as forward. In the water, where the weight of its body is made less by the buoyant effect of the water, it moves very readily. In its natural habitat the crayfish walks slowly about in search of food. But if an enemy threatens, it retreats rapidly by bending the abdomen under very quickly and forcibly, using it as a paddle to pull the whole body backward. The jointed structure of the abdomen and the powerful muscles found in it are adaptations that make possible this unusual method of moving.

***Growth.** The hard exoskeleton of the crayfish does not grow, as does the rest of its body. From time to time the animal molts; that is, it sheds this shell. It molts at least seven times during its first summer and once each year thereafter. After it has shed the old exoskeleton and before the new one hardens, it is without defense and must remain in hiding. Its chief enemies at this time are other crayfish. Soft-shelled crabs are those crabs which have just shed their old shells. Their new shells have not yet hardened.

Economic value. Crayfish are considered to be a delicacy in many countries and in some parts of the United States. They are of some value as scavengers,[1] eating decayed vegetation and fish. Crayfish sometimes do damage by digging tunnels in levees, which so weakens the levees that they sometimes break under the strain of high water.

Self-test on Problem XI–B. **1.** The crayfish is difficult to see in the water because of its __(?)__.

2. The crayfish is most commonly found *on land.*

3. The crayfish protects itself from attacks by means of its *sting.*

4. What looks like the crayfish's tail is its __(?)__.

5. The *crayfish* is used by man for food.

Problem XI–C · What are Some Adaptations of the Insects (Phylum Arthropoda, Class Insecta) which Enable them to Compete successfully for Energy?

Insects the commonest of all animals. Insects are found practically everywhere. They live in the soil and in water, as well as on the surface of the earth. Many species of insects occur in the shallow waters of the oceans. They have solved the problems of life in the deserts and in the arctic regions. They are so abundant in tropical countries as to present some of the most serious problems and difficulties in the way of man's settlement of these regions. About four fifths of all the kinds of animals known are insects. Over five hundred thousand species of insects have been identified. Moreover, so many new species are being discovered and described that entomologists[2] estimate the number of species now living as at least a million.

Experiment 45. What are the general characteristics of a typical insect? Use a live grasshopper (Fig. 124) for these observations.

1. Note the three body regions: head, thorax, and abdomen (Fig. 125). How do they differ from one another? Is the head movable? Which part of the body shows most clearly the jointed nature of the exoskeleton?

[1] *Scavenger* (scav′en jer): an animal that eats refuse or carrion or both. *Carrion* (kair′i un): decaying animal matter.

[2] *Entomologist* (en to mol′ o jist): a scientist who makes a special study of insects.

2. How many legs are there? To what part of the body are they attached? How many wings are there? Lift the outer pair carefully. How do the inner wings differ from the outer wings? To what part of the body are the wings attached?
3. Can you observe a movement of the abdomen? The movement is caused by breathing. Look along the sides of the abdomen for the tiny openings (spiracles) which lead to the breathing tubes (tracheæ). How many are on each segment? Have all segments such openings?
4. On the head find the compound eyes. Are they large or small in comparison with the rest of the head? Examine with a magnifying glass to see the many small parts which make up a compound eye, or place a piece of the surface of the eye under a compound microscope. Near the eyes are the jointed antennæ, or feelers. How does the insect use them? Between the compound eyes do you find any simple eyes (ocelli)? How many? Try to feed a live grasshopper a piece of grass. Describe its method of eating. How many mouth parts can you distinguish? How do its jaw movements differ from yours?

Cornelia Clarke

FIG. 124. The grasshopper can jump about a hundred times its length. How does its ability to jump aid in its survival?

Look over the four sections you have just completed and list four or five characteristics by which you think an insect can be distinguished from any other animal. Examine other insects to see whether all possess the characteristics of insects which you have listed.

Adaptations which aid in survival. General structure. In the insects we see the highest development of the exoskeleton. It contains horny material (called chitin (see Glossary)), which is thought to give strength and firmness. The exoskeleton has several advantages: (1) it is sufficiently hard so that the insect is not readily crushed; (2) it is light enough to enable the jumping insect to leap long distances; (3) it is so tough that it does not break when the insect strikes the ground. A great disadvantage

of such a skeleton is that it does not grow as the rest of the body does. Hence it has to be shed from time to time. The muscles are

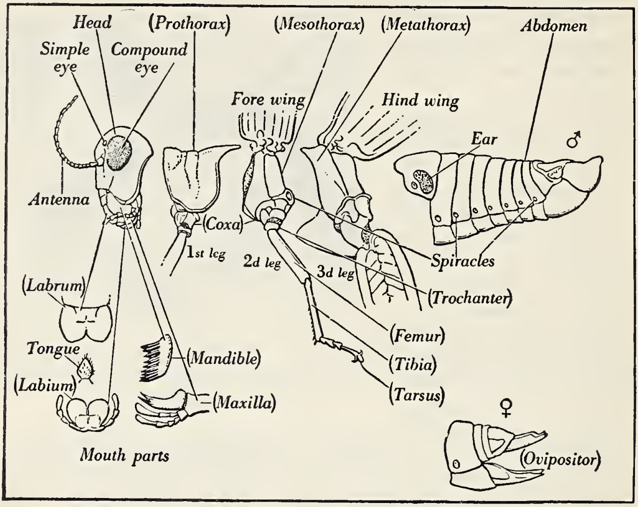


FIG. 125. External structures of the grasshopper. Is the grasshopper on the left in Fig. 124 a male or a female?

attached to the inside of this exoskeleton and are very powerful. A honeybee is said to be able to fly from daylight to dark without rest. Ants and wasps may carry other insects weighing much more than they do.

How insects are classified. There are certain distinct differences between butterflies, grasshoppers, bees, and beetles that enable us to recognize any of them at a glance. Some other insects will require more careful study before we can place them with their nearest relatives. Scientists have divided the insects into some fifteen orders on the basis of the kind and number of wings they have, the kind of mouth parts, and the type of metamorphosis they pass through. The following table describing six of the orders which are most important to man may help you to identify some of the insects you have not previously known:

Order: Orthoptera. Four wings, outer pair meeting in a straight line along the back, inner pair folded. Chewing mouth parts. Incomplete metamorphosis. Examples: grasshopper, cricket, walking-stick, cockroach.

Order: Lepidoptera. Four wings covered with scales. Mouth parts modified to form a long sucking tube. Complete metamorphosis. Examples: moth, butterfly.

Order: Coleoptera. Four wings, the outer very hard, the inner large and folded. Chewing mouth parts. Complete metamorphosis. Examples: beetles, like the June bug, potato beetle, firefly, ladybug.

Order: Hemiptera. Four wings. The outer wings with the posterior half thin and transparent. Sucking mouth parts. Incomplete metamorphosis. Examples: squash bug, stinkbug (see *bug*, in Glossary).

Order: Diptera. Two wings. Mouth parts for piercing or sucking. Complete metamorphosis. Examples: house fly, mosquito, blowfly, stable fly.

Order: Hymenoptera. Four membranous wings. Mouth parts adapted for sucking and chewing. Complete metamorphosis. Examples: bee, ant, wasp.

*__Protective coloration and protective resemblance.__[1] The body of an insect is often adapted to resemble its surroundings either in color or in form (Fig. 126). Many of the caterpillars that feed on vegetation are green. The beetles that live in goldenrod blossoms are of the same bright shade. The walking-stick is long and slender like the twig of a tree, which it likewise resembles in color. The grasshoppers commonly found in fields are greenish, while those of the roadside are a dusty brown. The insect possessing such color adaptations is not easily seen and hence is more likely to escape its enemies than if its color did not blend with its environment. Certain insects, which have no stings or other means of protection, closely resemble bees. When molested these insects go through the same motions that the bee makes in using its sting. It is probable that these fortunate adaptations of color and behavior aid these harmless insects in survival. Still other insects closely resemble in appearance certain forms which birds avoid, probably because the birds have found them unpleasant in taste. Thus the viceroy butterfly, which birds readily eat, is more likely to escape because it closely resembles the monarch butterfly, which many birds have learned to avoid.

[1] *Resemblance* (re zem'blans): a likeness, or similarity.

A. M. N. H.

Fig. 126. *A*, larva on a twig; *B*, leaf butterfly. What advantage may these organisms derive from such protective resemblance?

In connection with these and other examples of protective coloration or protective resemblance, it must not be thought that any insect or other organism consciously adopts color or behavior in order to secure protection. Moreover, the organism does not purposely seek an environment which affords the best use of the coloration or resemblance that it happens to have. The probable reason that there are so many examples of protective coloration and protective resemblance is that among all the organisms which have lived throughout the millions of years that life has been on the earth those which happened to have the best protective coloration or protective resemblance survived in greatest numbers and produced others marked like themselves. Fewer of those which were without these advantages were able to escape their enemies and to reproduce their kind.

It must be remembered, however, that every living thing does have its enemies. Moreover, these enemies find their prey, whether the latter has protective resemblances or not. Protective resemblances alone, therefore, would not enable an organism to survive. Each kind of organism must be able to produce enough young to survive in spite of its enemies. The ability to produce a sufficient number of young is therefore a more important factor in survival than the possession of protective resemblances.

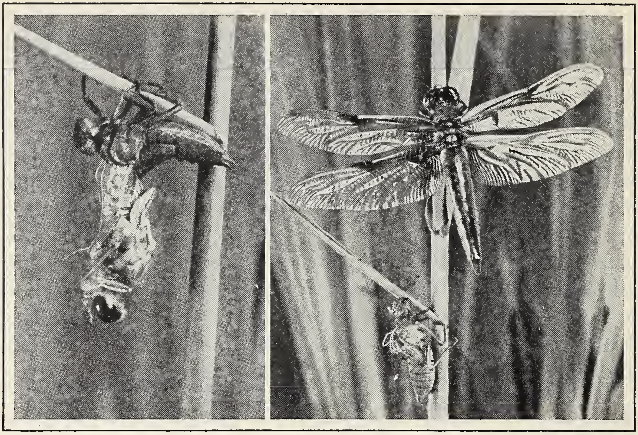
Adaptations for movement. Insects always have six legs and usually have two pairs of wings to aid in locomotion. Since, however, various insects live in such different environments as the air, the ground, the water, and wood, the wings and legs of different species must differ greatly to enable each kind to survive in its habitat. Thus the moth flies much and walks very little, since it has large wings and small weak legs. The grasshopper escapes from its enemies by jumping, because its hind legs are very long and strong. Many of the grasshoppers supplement their jumping with flying. The honeybee has relatively small wings, but these are operated by powerful muscles that enable it to fly for considerable distances at great speed. Aquatic insects, such as water boatmen, diving beetles, and back swimmers, have their hind legs modified for movement in the water.

Experiment 46. What is the appearance of the scales on the wing of an insect? Examine through a microscope some of the scales which come off on your fingers when you touch a moth wing or a butterfly wing. Describe their appearance in complete sentences or by means of sketches.

Metamorphoses. The period of time that must elapse before the eggs of insects hatch varies greatly with the species. Many of our insects pass the winter in the egg stage, while other insect eggs hatch in a few days.

*Many insects, such as butterflies, bees, ants, moths, and flies, after hatching from the egg pass through a complete metamorphosis of three stages: larva, pupa, and adult (Fig. 127). Others, like the grasshopper and cricket, go through an incomplete, or gradual, metamorphosis. An incomplete metamorphosis is one in which the changes in appearance as the young develops into an adult are slight and in which the young animal at all times looks much like the adult.

The life history of a moth illustrates complete metamorphosis. The colored plate opposite page 200 shows the life history of the gypsy moth, which is a pest in the New England states. It was brought to this country by an experimenter who hoped that the insects would prove valuable for silk production. Some of the insects escaped unnoticed. Within twenty years they had be-

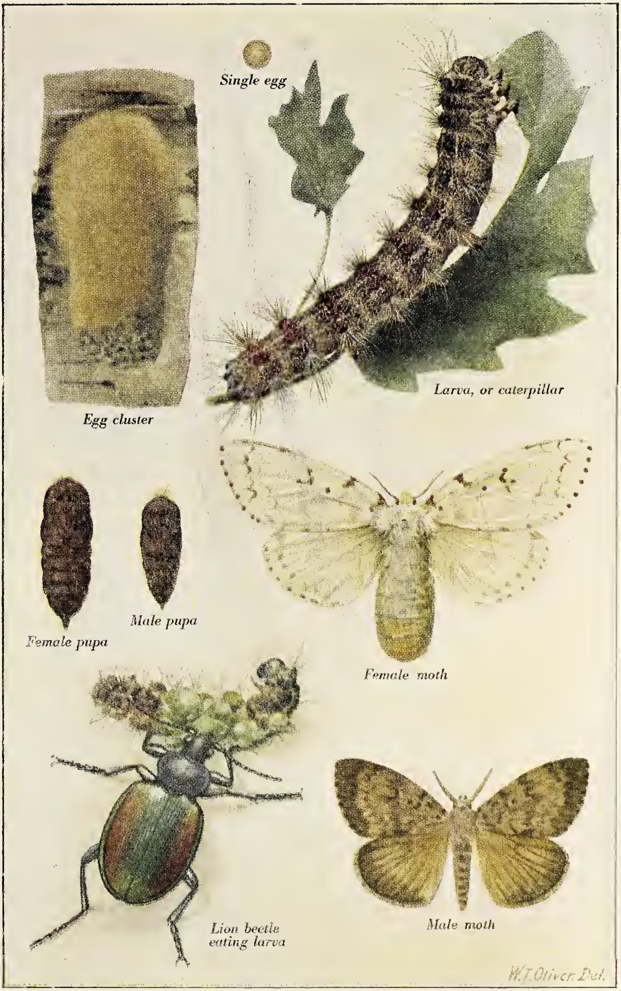


Ernst Krause

FIG. 127. A dragon fly emerging from its pupa case (left) and drying its wings (right). What simpler animal likewise undergoes complete metamorphosis?

come serious pests in Massachusetts. Fortunately control measures have prevented them from spreading over all the country.

The gypsy moth lays its eggs in July or August, in masses of four hundred to five hundred, usually on the bark of trees. The eggs remain over winter, hatching about the first of May. The tiny caterpillar begins at once to eat the tree leaves and grows very rapidly, molting three or four times. By the end of the summer it has reached a length of almost three inches. Then it stops eating and crawls about in search of a suitable place to spend the next stage of its life. It spins a few silken threads, which attach one end of the body to a support, or sometimes it spins a complete cocoon about its body. Then the larva within the cocoon molts for the last time, and develops a very different sort of covering, the pupa case. The pupa stage is often called the resting stage because no activity can be seen. But many changes must occur in this period of the moth's life cycle, for within the pupa the caterpillar is transformed into a moth. The moth emerges from the cocoon in ten days or two weeks. It lives for a few days until the eggs are laid and then it dies.



The life history of the gypsy moth. How does it illustrate complete metamorphosis?

Many of our moths and butterflies pass the winter in the pupa stage. The adult monarch butterfly migrates as the birds do. Some of the anglewing butterflies spend the winter in the adult stage, hiding themselves in brush piles or similar protected spots. Many moths hibernate as larvæ or pass the winter in the egg stage. But for the most part the pupa affords the best protection against both hungry enemies and the cold. It may be placed under a bit of bark or close against the side of a twig or even buried in the ground. Many of the moths further protect the pupa by spinning a cocoon of silk about it. Some of the moths and all the butterflies pass through the pupa stage in a shell-like case called a chrysalis.

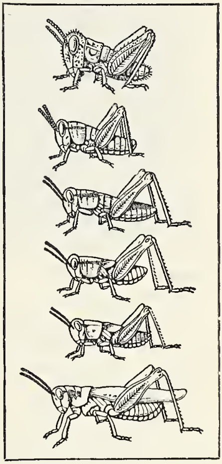


Fig. 128. How do these pictures indicate that the life history of the grasshopper illustrates incomplete metamorphosis? [1]

The life history of a grasshopper illustrates incomplete metamorphosis. In early fall the eggs of some of the common grasshoppers are laid eight or ten together in holes which the female digs in the ground in pastures, along roads, and in fields. Here they remain all winter. In the central states they hatch about the middle of May. The little grasshopper, called a nymph, is a queer animal having head and thorax resembling those of its parents but having only one pair of legs sufficiently well developed to be used, and lacking wings (Fig. 128). It grows rapidly, soon reaching as great a size as its exoskeleton will permit. There is but one thing for it to do then — get out of the old armor and grow a new suit. The little grasshopper settles down on the ground or on the grass where it will be hidden from enemies. The exoskeleton splits down the back, and little by little the insect pulls itself out of the old shell. This process, called molting, may require from twenty minutes to several hours. While the new skin is still soft and elastic, the insect increases considerably in size. A few hours

[1] From Packard's *Textbook of Entomology.*

later, when the exoskeleton has hardened sufficiently, the grasshopper is ready to go food-hunting again. All insects, and indeed all arthropods, must molt their hard external coverings in order to grow. The grasshopper passes through five molts before it reaches adult size.

Insects well fitted to compete for available energy. It is stated by some scientists that insects are better fitted to survive than are other animals, even including man. There are reasons why insects can compete successfully for available supplies of energy.

1. They have ability to escape from enemies. Most of them are small and can crawl into or under very tiny shelters, where they will escape notice. Many have remarkable powers of flight, which carry them from danger. Many have protective coloration or protective resemblance of one sort or another.

2. They have excellent powers of locomotion. Many kinds can fly and crawl so steadily and rapidly that they can spread quickly into new territory. Many of our Western states have experienced plagues of grasshoppers that migrated from regions where food was scarce.

3. They are able to use many kinds of food for which other animals do not compete. The larvæ of certain wood-boring beetles feed on dry wood. The clothes-moth larva eats wool and fur. Bees and butterflies suck the nectar from flowers. The maggot of the house fly lives in decaying organic matter.

4. They are able to exist for long periods without food. If food is not readily available, many insects can live for months without it. A flea has been observed to live more than a year without food, and yet at the end of that time it was able to hop vigorously.

5. They are able to reproduce at rapid rates. Hundreds and sometimes thousands of eggs are laid by one insect. The young of certain species hatch in a few days, and may reach maturity and be ready themselves to lay eggs in two or three weeks. A single house fly beginning its reproductive activities in early spring might have over five billion descendants by the end of the summer if all lived and reproduced (Fig. 129). It is fortunate that insects like the house fly have many enemies.

6. Their enemies are sometimes absent, or some may have few enemies. Many of the insects that are the most destructive crop pests thrive because their enemies are lacking in the regions to which they have been carried. The gypsy moth is not considered an important pest in Europe, for in Europe there are many birds and insects that feed on it. But when this moth was brought to the United States, it spread very rapidly because sufficient numbers of its enemies were not present.

7. There is often an unusual abundance of insect food. Man's activities in planting such crops as corn, wheat, and garden plants have helped to increase the numbers of insects by providing them with large areas of food. The Colorado potato beetle is a good example. When the pioneers began to settle the Middle West, the beetle was found eating the leaves of wild plants. The settlers cleared land and planted potatoes. The beetle found thus an abundance of food that it liked better than the weeds. It no longer had to hunt for food and could produce brood after brood in the same potato patch. Now it is a pest to every potato-grower in the United States.

A. M. N. H.

FIG. 129. A comparison of the American Museum of Natural History building and the possible volume of fly descendants from one pair of parents in nine generations. Why are such numbers not really produced?

8. They usually have a protected infancy. The fact that many insects spend part of their lives protected by a pupa case which is hidden underground or under the bark of a tree is an aid in increasing their numbers. In the pupa stage insects are defenseless and would be easily found by enemies and destroyed if they were not concealed. One of the pests recently introduced, the Japanese beetle, pupates[1] in the ground, where it is not easily reached.

Self-test on Problem XI–C. **1.** We say that the insect is a very successful animal because (1) every insect is able to thrive in its environment; (2) its exoskeleton makes it difficult to kill; (3) different kinds of insects can fly, crawl, jump, and swim and therefore are found wherever the other animals can live; (4) insects have been on the earth millions of years; (5) some insects have protective coloration.

2. Name three advantages and one disadvantage of the insect exoskeleton.

3. *Like* the spider, an insect has *eight* legs.

4. Which of the following animals illustrate complete metamorphosis: (1) moths; (2) sponges; (3) grasshoppers; (4) butterflies; (5) house flies; (6) ants; (7) bees; (8) crickets?

[1] *Pupate* (pu′pate): to develop through the pupal, or pupa, stage.

5. In *complete* metamorphosis the changes which the young animals undergo are slight.

6. The young animals which undergo *complete* metamorphosis always look much like the adult forms.

7. *Some* insects and crustaceans must shed their exoskeletons from time to time.

8. State at least six ways in which insects are well fitted to compete for available energy.

9. *Some* scientists believe it possible that there may be insects on the earth after man has become extinct.

10. Probably the chief reason for the survival of great numbers of insects is that (1) these animals produce enormous numbers of young; (2) many insects have protective coloration; (3) many insects have protective resemblance; (4) all insects have exoskeletons; (5) insects can live on a wide variety of food.

Self-test on Biological Principles. What evidence can you cite from this chapter which tends to prove the principle "Every living thing has enemies among the other living things"?

Self-test on Organization of Facts. Compare the crayfish and the grasshopper (see "Suggestions for Effective Study," p. xvi).

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Which of the phyla of animals that we have studied thus far is of greatest economic importance to man? Probably not all the members of the class will agree in this choice. Collect from as many sources as you can facts which will help you to defend your selection.

2. In what ways does the ability to move about help the grasshopper?

3. A pantry infested with ants or cockroaches may be freed of the pests by dusting borax freely around on shelves and in cracks. Can you explain?

4. Lobsters and crabs are shipped across the country packed in wet seaweed or straw. How can they live so long out of water?

5. How many different kinds of functions can insects perform with their legs?

Exercise on Scientific Method (Planning New Observations). Dragon flies are sometimes called snake-feeders because of the belief that the insects carry food to sick snakes. The insects are also called darning needles because some people believe that they will sew one's eyes and ears

shut. To what questions concerning the structure and habits of the insect should you need to find answers in order to show that both these beliefs are unfounded?

Project 13. To find out whether all insects have the same number of legs, wings, antennæ, and the same number and kind of eyes as the grasshopper. Examine with a hand lens or a microscope as many different kinds of insects as you can find, for example, a house fly, a blowfly, beetles of various kinds, a honeybee, a wasp, a bumblebee, a butterfly, a moth. Draw sketches to show the kinds and positions of legs, wings, antennæ, and eyes of the various insects. Do the insects of the same order — for example, beetles or flies — have the same kinds and positions of eyes? of wings? of legs? of antennæ?

Project 14. Collect as many cocoons and chrysalises as you can find. Store them over winter in a protected place out of doors. In January or February bring them inside and place them in a cage. Try to identify the moths and butterflies that emerge.

Special Reports. 1. Describe the division of labor in a honeybee hive, showing work done by the queen bee, the workers, and the drones. Report on the construction of the honey comb and the brood comb.

2. How do crickets chirp? Do other insects which make noises produce them in the same way?

3. The insect we call a grasshopper is truly a locust. What plagues of locusts have been recorded in history?

4. What is a cicada? a seventeen-year locust?

Chapter XII · The Animals with Spinal Cords

Questions this Chapter Answers

How did animals come to be classified as they now are?

Are fish ancient or recent animals?

What are some important adaptations of fish?

What are some of the life problems of Amphibia, and how are they equipped to meet these problems?

What are some facts about ancient and modern reptiles?

Why are birds successful animals?

What are some facts and theories about bird migration?

Are mammals more or less ancient than reptiles?

How are mammals fitted to compete for energy?

What are the important orders of mammals?

Of what economic importance are these various animals?

Problem XII–A · How are the Higher Animals Equipped to Compete for Energy?

The animals with spinal cords. None of the animals in the nine phyla which have been discussed in the preceding chapters has any bones (Fig. 130). Some, such as the echinoderms, the crustaceans, and the insects, have supporting skeletons; but these skeletons are outside not inside their bodies. The body of every animal higher than the insect is built around a bony framework which to some extent protects the internal organs and upon which the muscles act to move the body. Moreover, unlike the animals already discussed, all these higher animals have spinal cords, and all but the simplest of these have backbones, or vertebral columns. These animals with backbones are the fish, the amphibians, the reptiles, the birds, and the mammals (Fig. 130). Attached to the vertebral column of each of these animals are the skull, the bones of the four limbs,— that is, the arms and legs or the fins,— and usually several ribs.

From very early times it was recognized that the animals which we now call vertebrates could conveniently be classed together. In the fourth century before Christ, Aristotle, a famous Greek,

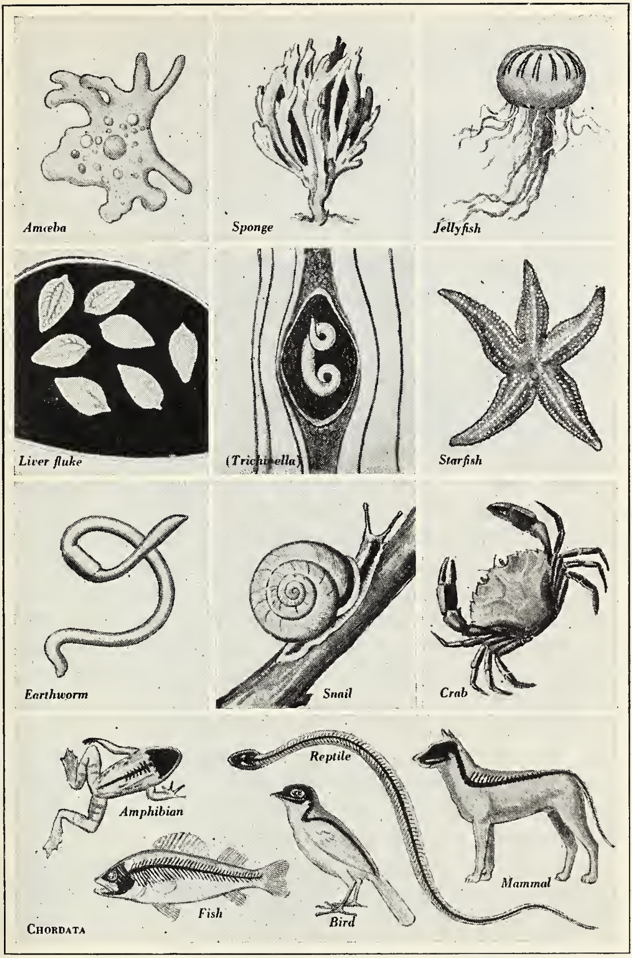


FIG. 130. From the lowest to the highest animals. Self-test on Organization of Facts: Can you name the phylum for each of the first nine of these animals? How many other examples of animals in each of the first nine phyla can you name?

grouped them together as the animals which had blood, because he thought that the simpler animals did not have blood. Centuries later it was found that the "bloodless" animals did have blood, although in the ones then known it was not red. Because of this discovery the scientists changed their basis of classification and called an animal a higher animal if it had red blood, and a lower one if it had colorless blood. This basis for grouping served until a little more than a century ago, when Cuvier, a French naturalist, found that some of the animals which are obviously not higher ones have red blood. This discovery made necessary a new way of distinguishing the two great groups. They were next distinguished as bony animals and animals without bones. When later this distinction proved unsatisfactory, animals were classed as vertebrates and invertebrates, that is, animals with or without backbones.

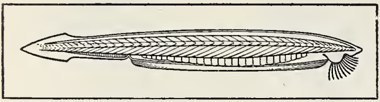


FIG. 131. Special Report: Consult an advanced zoology textbook or an encyclopedia for the characteristics of this primitive chordate, *Amphioxus*

The term *vertebrate*, however, has not been entirely satisfactory because of certain primitive animals which resemble the vertebrates closely yet have no true bones. These animals have, in the same position as the backbone of vertebrates, a soft rodlike structure (notochord) which supports the nerve cord along the dorsal side of the body. A few of these forms are found in the oceans today. They are not fish; yet they resemble fish more than they do any of the simpler animals (Fig. 131). They are believed to resemble the ancestors of present-day vertebrates, which were probably fishlike forms living in the ocean.

In fish, which are the simplest vertebrates, the rod which supports the nerve cord is made up of many small bones, or vertebræ. These vertebræ together make up the backbone, which completely incloses and protects the spinal cord.

*Rather than make a separate phylum of the animals which are lower than fish yet are more like them and the higher animals than they are like the invertebrates, biologists have come to use the name *chordates* to include vertebrates and these simpler

forms. The *chordates* therefore include all animals having a spinal cord, whether this cord is protected by vertebræ or by cartilage.[1]

The invertebrates were on the earth many ages before there were any vertebrates. Yet here and there are found fossils of vertebrates which lived millions of years ago (Fig. 132).

A. M. N. H.

FIG. 132. Jaws of an ancient shark. These gigantic animals lived about forty million years ago in the warm ocean which then covered Florida and neighboring regions. They grew to be ninety feet long. Their descendants of the present day sometimes have a length of forty feet. How many reasons can you suggest which might explain how these enormous fish became extinct?

Self-test on Problem XII–A. **1.** The distinguishing character of the animals in the highest phylum as compared with all others is the possession of a __(?)__.

2. *None* of the lower animals *has* red blood.

3. Name five groups of animals possessing backbones.

4. The term *vertebrates* includes all the *chordates*.

5. The *vertebrates* are older forms; that is, they have been on the earth longer than the *invertebrates*.

6. Vertebrates are known to have lived on the earth for *hundreds* of years.

Problem XII–B · What are Some Adaptations of the Lowest Vertebrates (Phylum Chordata, Class Pisces) which Make them Successful Animals?

Fish are successful animals. At one time in the history of the world, fish were the most conspicuous and most highly developed form of animal life. This period is called the Age of Fishes. Fossil remains of these ancient animals show that they were much like present-day fish. The adaptations which fitted them for life in the water were so successful that they have continued, little

[1] *Cartilage* (kar'ti laj): a tough elastic animal tissue; gristle.

changed, for millions of years. Some of these adaptations, which we think of as being peculiarly fishlike, are the fins used in swimming, the gills for breathing, and the covering of scales or plates.

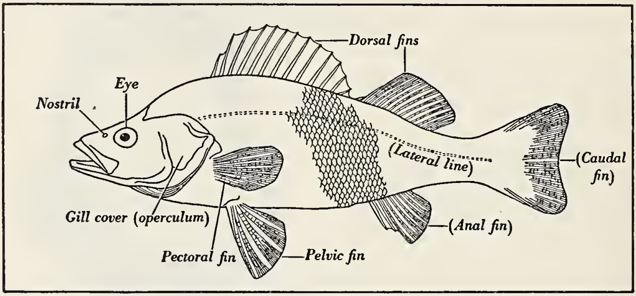


FIG. 133. **Special Report:** What is the function of the lateral line? (Consult an advanced zoology textbook)

Although most of our fish have bony skeletons, some of the lower fish of the present time have skeletons of cartilage instead of bone. Examples are the sharks and skates. Another group of fish which resembles primitive forms more than it does most of the present forms includes the sturgeon, the gar pike, and certain others found mostly in the Mississippi and the Nile. These are covered with bony plates instead of scales, and in this respect they resemble the armored fish, which lived millions of years ago.

***Locomotion.** Most fish need to be able to swim rapidly, both to secure food and to escape from enemies. They have many adaptations which enable them to move quickly through the water: (1) their bodies are more or less flattened from side to side and taper toward both ends; (2) they have no projecting shoulders or hips to spoil the streamline; and (3) the slimy covering over their bodies decreases their resistance to the water.

Experiment 47. What are some of the characteristics of a living fish? Place a small fish in a jar of water. Make a sketch of the fish as seen from the side. Label the eyes, mouth, jaws, nostrils, gill covers (opercula), and fins. Compare its external features with those of the perch in Fig. 133. How many fins has it? Watch it swim. What fin or fins do most of the work of moving the fish? What fins does the

fish use in stopping? in turning to one side or the other? Can the fish remain motionless without moving the fins? What fins are in

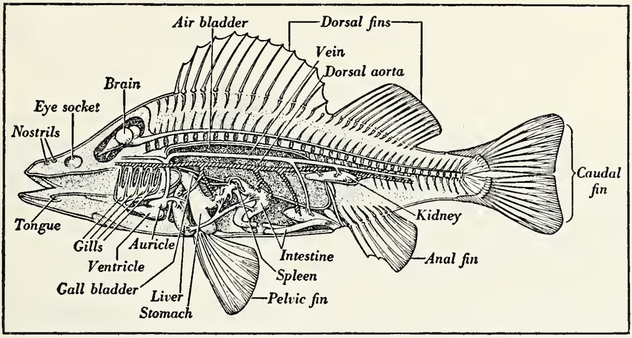


FIG. 134. What internal organs of the fish are also possessed by the earthworm (Fig. 112, p. 177)?[1]

pairs? What are the fins along the dorsal line used for? Does this fish have scales? Are they separate, or does each extend partly over the next, like shingles on a roof?

Can the fish move its eyes? Has it eyelids? What advantage does the fish derive from having its eyes placed as they are?

Pull away from the head the gill covers of a preserved fish or a fresh fish from the market. Note how the gills are attached. Cut away the gill covers. How many gills are there on each side? Note the filaments, or gill threads. Which way do they point, toward or away from the mouth? Can you see an advantage in this arrangement? Note on the inner edge of the gill arch the bony projections. These are gill-rakers, for straining out food and for catching solid objects which might injure the gills. Make a diagram showing the location of the gills. Make another sketch of a gill.

Dissect a fish in much the same way that you dissected an earthworm. Make a sketch to show all the organs you are able to find (Fig. 134).

When such a fish as the goldfish swims slowly, it seems to be moving all its fins. But when it wishes to move rapidly, it does so by powerful side-to-side strokes of its tail. The other fins seem to be used principally for guiding, stopping, and balancing the animal.

[1] From Meier and Meier's *Essentials of Biology.*

The fins are of two kinds: those on the middle line of the body, (as the dorsal, the anal,[1] and the caudal[2]); and those that occur in pairs, as the pectoral and the pelvic. The paired fins are attached to the rest of the skeleton in the same way as are the legs of other vertebrates. For this reason we say that they are homologous to the corresponding limbs of different vertebrates. *Homologous organs* are organs that have the same structure or that originate from the same part of the body. The pectoral fins of a fish, the arms of man, the front legs of a dog, and the wings of a bird are homologous. The pelvic fins of a fish, the legs of man, the hind legs of a dog, and the legs of a bird are homologous.

Most fish are prolific. The cod and the eel may lay as many as ten million eggs at once. Why then do not the cod and the eels entirely fill the oceans? Several reasons are apparent. In the first place all the eggs do not develop into young fish. Then, too, both the eggs and the developing young are eaten in great numbers by birds, larger fish, crustaceans, and other water animals. Even the parent cod often devour their own young. So many are the dangers that but a few ever develop into mature fish.

Economic importance of fish. Fish are chiefly valuable to man as food. Several thousand kinds are eaten; in the United States, Alaska, and Canada the salmon, cod, tuna, and halibut industries are worth many millions of dollars a year. Fish are used extensively for fertilizer and are valuable sources of oil and glue; oil extracted from fish livers is an important source of vitamins. Isinglass is prepared from the air bladders of sturgeon, cod, and other fish.

Self-test on Problem XII–B. **1.** In an earlier age fish represented the *highest* development of animal life.

2. *All* fish have skeletons made of bones.

3. The fish which are covered with bony plates instead of scales are a *more* primitive form than those with scales.

4. The *fish* has two pairs of fins which are homologous to arms and legs.

5. Fish are of chief importance to man as __(?)__.

6. Fish lay *few* eggs because the chances that each egg will develop into an adult fish are very *small.*

[1] *Anal* (a'nal): having to do with the anus, or opening from the food tube.
[2] *Caudal* (caw'dal): having to do with the tail.

Vacation-Time Biology

WE FOUND the strings of toad eggs in the spring shortly after they had been laid. Thousands of them were attached to sticks and stones in the relatively quiet water near the edge of the stream.

We watched them develop into tiny wiggling tadpoles, so numerous that they formed a black patch on the stream bottom. We found eight similar black

Cornelia Clarke

Fig. 135. How many means by which the toad escapes its enemies can you name?

patches within a half-mile of the first. What thousands of toads there would be later, we thought! But we were to learn much before the summer ended.

The tadpoles grew in size, until the black mass on the stream bottom covered about two square yards. But soon we noted that the patch was getting smaller. What was happening to the tadpoles? Where were they going? We watched to see. We saw that many in hurrying away from moving objects on the bank, which might be enemies, got into the swifter current and were swept down into the deep holes, where no doubt they were devoured by trout. Others were trampled by the cattle which came to drink. Hundreds of others were devoured by garter snakes which came daily to gorge themselves upon this easily captured prey. No wonder the black patch of tadpoles was visibly shrinking, almost from day to day.

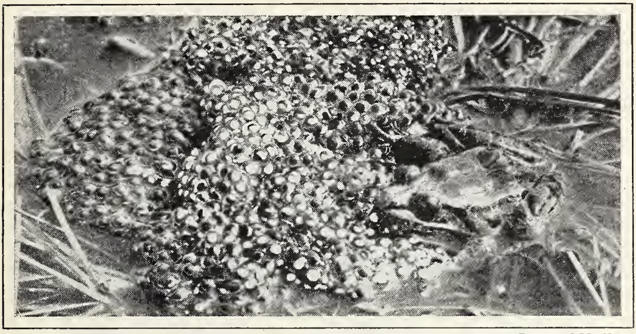
Finally in late July the tadpoles that were left had developed into toads the size of a small kernel of corn and had begun to leave the water for the gravel bar (Fig. 135). Here they were met by a flock of chickens which, in spite of the fact that the color of the toads matched that of the gravel, picked them up by dozens when they hopped. Not many survivors, it seemed, would succeed in reaching the grass beyond the gravel bar. There were snakes, we knew, in that grass, and crows in the near-by fields. Later we found dozens of small toads which had been killed by automobiles while crossing the road close by. Certainly there would be few to lay their eggs in the stream next spring. Now we knew why toads need to be prolific in order to survive.

A, New York Zoological Society; *B*, A. M. N. H.

Fig. 136. Two lizard-like amphibians. **Exercise on Scientific Method (Making Inferences):** *A* has gills, but *B* does not. What do you infer from this fact concerning their respective habitats?

Problem XII–C · What are Some Adaptations of the Frogs and their Relatives (Phylum Chordata, Class Amphibia) which Make them Successful Organisms?

***Characteristics of amphibians.** The amphibians occupy a position between the water-dwelling vertebrates and the land-dwelling vertebrates (Fig. 136). The word *amphibian* means "an animal that lives a double life" and refers to the fact that the young of most of the species — for example, the frog and the toad — are hatched in the water and breathe with gills, while



Lynwood M. Chace

Fig. 137. Leopard frog and its eggs. Part of the egg mass here has been lifted above the water in order that it might be photographed. How do you explain the fact that the egg mass is larger than the frog?

the adults live on land and breathe with lungs and through the skin. The adults of many of the lower forms, however, breathe with gills all their lives. The mud puppy, for example, never develops lungs.

Some of the amphibians resemble snakes, and others look like lizards. But, unlike snakes and lizards, most of the amphibians have smooth, slimy skins without scales. All go through complete metamorphoses.

***How toads and frogs develop.** The development of the frog is similar to that of all other amphibians. Members of the frog family are prolific (Fig. 137). One toad observed in the laboratory laid 6350 eggs in one night. Frog and toad eggs are fertilized by the male as they leave the body of the female. They hatch in a week or ten days. If you watch carefully from day to day, you can observe some of the changes that occur (Fig. 138). The young tadpole at first has neither gills nor mouth. It fastens itself to weeds or sticks in the water by a sucker on its head, and for a few days is nourished by the yolk of the egg from which it came and which is inside its food tube. Soon external gills and a mouth develop. Now it swims about, using its tail as a fish does, and eating large quantities of plant material, such as algæ.

You will have to watch carefully for the external gills, for they

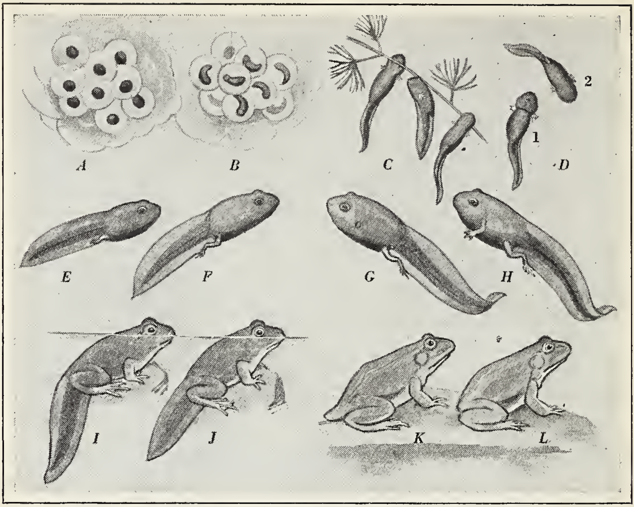


FIG. 138. Can you explain this series of diagrams showing the life history of a frog? Does the life history of the frog, like that of all other Amphibia, represent a complete or an incomplete metamorphosis? Explain

last not more than three or four days at the most. By that time internal gills have developed to take their place. These are covered by a fold of skin (the operculum), as in the fish. The water enters the mouth, passes over the gills, and out through a single opening (spiracle) on the left side of the body.

*The tadpole increases in size rapidly. The hind legs appear, first showing as little bumps near the tail and gradually getting longer. Somewhat later the front legs break through the skin. They were formed at the same time as the hind legs but remained beneath the skin for a while. All this time the tail has been getting shorter and shorter. It is gradually absorbed, and the food material stored in it is used to make other parts of the body.

Equally important changes have been going on inside the body of the tadpole. The lungs are developing as the gills are disappearing. A time comes when the tadpole has to come to the surface to breathe. The very young tadpole eats plant life almost

entirely, and has the very long coiled intestine of plant-eating animals. As it grows older and starts eating insects and worms, the intestine becomes shorter. The mouth changes greatly, too. The rather small rounded mouth of the tadpole, which was used to suck off pieces of plants, has become large and of a different shape, better adapted for catching insects and worms.

*When all these changes have occurred, the tiny frog or toad hops out on land. The length of time required for a tadpole to become an adult depends on the species and to some extent on the amount and kind of food available. Toads develop in two or three months. Most frogs, like the leopard frog, complete their development before the end of the summer. Green frogs and bullfrogs live two or even three years in the tadpole stage.

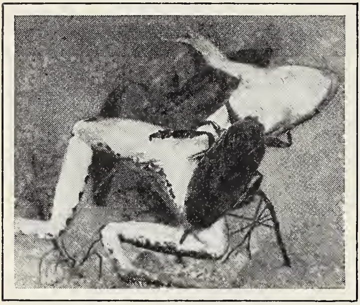
The metamorphosis of the frog or toad indicates that its ancestors were water animals. The fishlike tadpole, which can live in water only, develops into a frog, which can live on land and breathes air. This development of the frog offers evidence that slowly, over long periods of thousands of years, these fishlike ancestors became adapted to life on land.

Experiment 48. Is water a shelter for the frog? Place a frog in a jar containing five or six inches of water. In what position does it float? What parts of the body remain above the water line? Of what advantage is this? Move your hand quickly toward the frog. What happens? Describe.

Experiment 49. How can the frog stay so long under water? Place a frog in a jar of water. When it dives under and rests on the bottom, time it to see how many minutes it stays down. How does this interval compare with the length of time man can remain under water? Can you account for the difference?

Experiment 50. How are the legs fitted for swimming and jumping? Carefully examine the legs of a live frog. How many toes on each foot? Are both hind and front feet webbed? Put the frog in water, so that it can swim. How does it use its legs? Place it on the floor and watch it walk or jump. For what does it use each pair of legs now? Repeat until you are sure your answer is right. Make a sketch of the hind leg of the frog and beside it place a sketch of your own leg. Which parts of the frog's leg are longer in proportion to the total length than are the corresponding parts of your own leg? How would this form of the leg help in swimming and in jumping?

Experiment 51. How are bones moved? Remove the skin from the leg of a preserved frog. Note especially the large muscles of the upper leg. Examine one of these closely. Where is it attached to the bones of the leg? How does this help to move the bones? Note the tendons that extend from the muscle across the joint. What is their use? Can you find a muscle which draws the leg up? one which straightens it out? Make a diagram to answer the question asked at the beginning of the experiment.



Lynwood M. Chace

FIG. 139. The giant water bug finds its prey. How many kinds of enemies of the frog can you name which attack him out of water? under water?

Enemies. Besides man, who eats frogs' legs, the enemies of frogs also include snakes, fish, turtles, wading birds like herons and cranes, and a few insects (Fig. 139). The frog cannot fight its enemies, so must depend upon its protective coloration to serve as a means of concealment; or it must escape by jumping or swimming away. It may leap into the water and either swim some distance away or rest on the bottom until the enemy has gone. Some amphibians — for example, the leopard frog, the toad, and certain of the newts and salamanders — have poison glands in the skin. Some animals are made very sick or may even die as a result of eating these Amphibia.

***Economic importance of Amphibia.** Practically all Amphibia are of more or less benefit to man. Frogs are of considerable value, since they eat insects that would trouble man. But the toad is the most useful member of this class. It lives in our gardens or even in greenhouses and destroys countless insect pests. No less than eighty-three species of insects have been found in the stomachs of toads. One investigator estimated that a toad may eat twenty dollars' worth of cutworms (the larvæ of certain moths) in a summer, assuming that each worm does only one cent's worth of damage.

Internal structure of the frog. The frog provides a good illustration of the internal structure of a vertebrate. All the higher

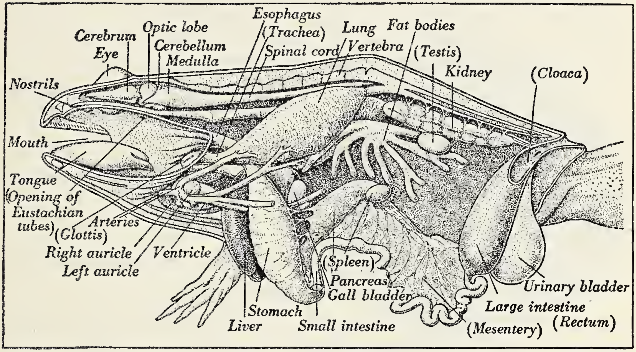


FIG. 140. The internal structure of the frog.[1] What internal structures do the frog and the fish (Fig. 134, p. 211) have in common?

animals, including man, have bodies built on much the same plan as that of the frog. Note carefully these structures in Fig. 140.

Experiment 52. What is the internal structure of a frog? Use a preserved specimen or kill a frog with chloroform. With the scissors remove the muscular wall of the entire ventral surface of the abdomen (Fig. 140). Keeping the point of the scissors high so as not to injure internal organs, cut through the pectoral girdle up to the throat, so that the heart is exposed.

Describe the heart (right and left auricle). Is the heart farther anterior (toward the head) or posterior (toward the rear end) than yours?

Locate and describe the lungs. In a fresh specimen put a tube into the opening in the throat and inflate the lungs.

Where is the liver? How many lobes has it? Can you find the gall bladder?

Trace the organs making up the alimentary canal — mouth, esophagus, stomach, small and large intestine, and cloaca. In the loop between the stomach and intestine find the pancreas.

Did you notice the thin tissue (mesentery) that holds the intestine in place? Look for blood vessels in it. Look also for the spleen, near the large intestine but not connecting with any organ.

[1] From Meier and Meier's *Essentials of Biology.*

The kidneys are large dark-red bodies on either side of the vertebral column. Near them you may find irregular fingerlike masses of fat. The presence of these will depend on the time of year. Why? What function do you think these fat bodies might serve?

Look in the body cavity for the large threadlike nerves which extend from between the vertebræ to the muscles of the leg.

Put the dissected frog into a jar of alcohol or of water and formaldehyde. You will want to look at it many times as you study the later chapters which describe the functions of the organs you have seen.

Self-test on Problem XII–C. **1.** *Some* amphibians spend all their lives under water.

2. *All* amphibians have four legs.

3. *All* amphibians breathe with gills during at least a part of their lives.

4. As a tadpole develops, its tail *drops off*.

5. From the life history of the frog, scientists believe that the *frog's* ancestors lived in the water like fishes.

6. A frog can sometimes escape being eaten by other animals because of its (1) poison glands in the skin; (2) protective coloration; (3) ferocious appearance; (4) formidable teeth; (5) spines.

7. The amphibian of greatest economic importance is the *salamander*.

Problem XII–D · How are the Snakes and their Relatives (Phylum Chordata, Class Reptilia) Equipped to Compete for Energy?

Ancient reptiles. At one time in the history of the world, many millions of years ago, the reptiles were the largest and perhaps the most numerous animals. Gigantic land-dwelling reptiles (dinosaurs) roamed the land. Fantastic reptiles, somewhat resembling snakes, lizards, or fish, inhabited the waters. Flying reptiles, some with a wing spread of twenty feet, glided through the air. Skeletons have been found of a huge plant-eating animal measuring eighty feet from nose to tail tip and weighing nearly forty tons (see Fig. 2, p. 5). It must have lived in the water, for it seems impossible that it could have carried such a huge bulk about over the land. Preying on such animals were smaller forms, smaller only by comparison, however, for certain ones stood twenty feet high and had teeth six inches long. All dinosaurs,

however, were not huge like the Tyrannosaurus and the Diplodocus (see Fig. 32, p. 56). Some were no larger than present-day lizards.

Further information concerning these reptiles was gained a few years ago when a scientific expedition into the desert regions of Mongolia found several fossil dinosaur eggs (Fig. 141).

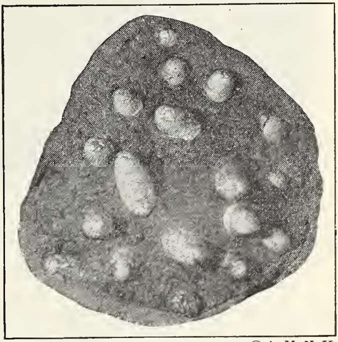


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Fig. 141. Fossil dinosaur eggs. The dinosaur that laid these eggs was about the size of a modern crocodile. It lived many millions of years ago. Can you explain how these eggs came to be preserved?

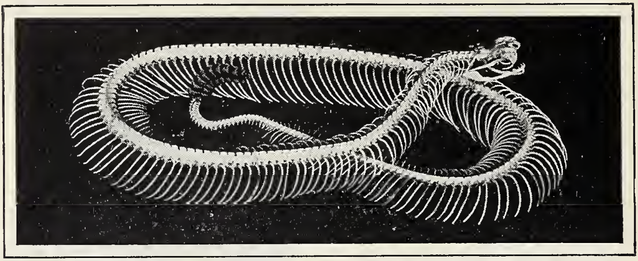
During the long period in which these animals were dominant,[1] conditions slowly changed. The swamps slowly dried up, and vegetation became much less abundant. The huge reptiles were unable to adapt themselves to the changing environment, and hence they finally became extinct. It is thought, too, that the small mammals which were just then coming into existence may have fed upon the eggs of the great reptiles, thus hastening their disappearance from the earth.

A few of the reptiles of earlier ages changed sufficiently, as the environment changed, to be able to survive. They were the ancestors of our present-day reptiles, and probably of the birds as well, as we shall see later.

Modern reptiles include some rather large forms (Fig. 16, p. 32). Certain sea turtles may weigh five hundred pounds. The python of Burma, which is the largest of the snakes, sometimes attains a length of more than thirty feet.

***Characteristics of reptiles.** The reptiles are vertebrates (Fig. 142) characterized by a scaly skin, and by the presence of lungs throughout their lives. This latter character marks an advance over fish and amphibians, for the lungs enable the reptiles

[1] *Dominant* (dom'i nant): prevailing over others; more important or numerous than others.



General Biological Supply House

FIG. 142. If you were to find this skeleton of a rattlesnake, could you at once place it in the correct phylum even if you did not already know to which phylum it belonged? Explain

to breathe air at all times and hence make it unnecessary for them to live in or near the water all the time. It is only as animals have developed structures which have made them independent of the water for support, for food, and for oxygen that they have been able to live in practically all parts of the world.

The reptiles have no metamorphosis, as do the amphibians. When the young hatch they closely resemble their parents. Nearly all reptiles lay eggs, which resemble birds' eggs, except that the covering is leathery instead of hard and brittle. The eggs are placed in some protected spot, as in a hole in the dirt or sand, under a pile of leaves, or even in a hollow decaying tree. Usually the parent pays no further attention to the eggs or young. However, some snakes, including the garter snakes and the rattlesnakes, and one lizard (the horned toad), keep the eggs within the body until they hatch, and the young are born alive.

The orders of reptiles differ considerably because of the adaptations necessary to enable them to survive. For example, snakes, having soft unprotected bodies, must be able to move rapidly, while the turtle, protected by a hard shell, finds speed unnecessary. The alligators and crocodiles and some snakes and turtles are adapted for spending most of their time in the water. The horned toad and certain tortoises are adapted for life in the desert. So widely different are the various reptile groups that we shall find it best to consider some of them separately.

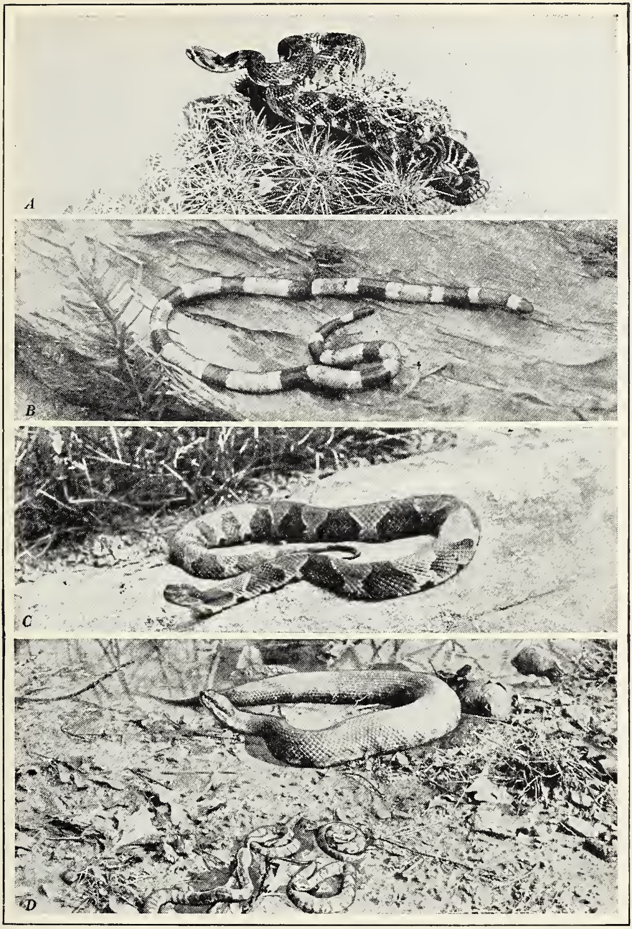


Fig. 143. Four poisonous snakes of the United States: *A*, rattlesnake; *B*, coral snake; *C*, copperhead; *D*, water moccasin and young. Of these only the rattlesnake is found in Canada. Can you explain how the protective coloration of a poisonous snake would be of value to the snake itself but might prove a disadvantage to other animals, including man? (*A*, photograph by Edwin Hogg, *B*, *C*, and *D*, photographs by New York Zoological Society)

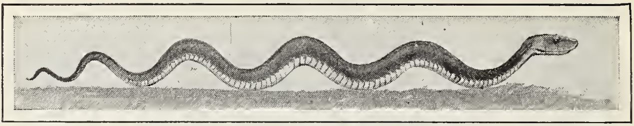


Fig. 144. Exercise on Scientific Attitudes: Does this picture correctly represent snake locomotion? What scientific attitudes (pp. 12–13) would one need to possess in order to determine whether or not the drawing is correct?

***Snakes.** Snakes are probably the most feared and disliked of animals. It is equally without doubt that they are decidedly useful animals. But so many people have permitted senseless fears to rule them that they wish to kill every snake they see. A small child is by nature no more afraid of a snake than it is of a dog or other animal. It learns to be afraid through watching the actions of older people and being told that a snake will bite or that it is poisonous. In regions where there are poisonous snakes perhaps such teaching is necessary (Fig. 143). But very few of our common snakes will harm one in any way. Most of them are timid creatures that are much more afraid of man than he should be of them. They will usually hurry to some safe hiding place if we will leave them alone.

Our common small snakes, such as the garter snakes and green snakes, are of benefit to man because they eat insects. Somewhat larger snakes, such as the bull snake and king snake, eat rats, mice, and rabbits. It is said that one bull snake is much more effective than several cats in keeping a barn free from rats and mice.

Adaptations for movement. Except for a few species of amphibians and of lizards, snakes are the only vertebrates which lack legs or similar appendages. The skeleton indicates, however, that their ancestors possessed legs. Snakes move by means of the large scales (scutes) on the underside. These grip the ground and hold the animal in position, while the muscles which run lengthwise in the body contract in a series of waves to help in moving (Fig. 144).

Other adaptations. Often while observing a snake we may see it stick out its forked tongue and vibrate[1] it very rapidly for a

[1] *Vibrate* (vi'brate): to move back and forth. *Vibration* (vi bra'shun): the act of vibrating.

Lynwood M. Chace

FIG. 145. Turtles hatching from eggs. Do you think this "nest" is near a stream or lake or is far from water? Explain

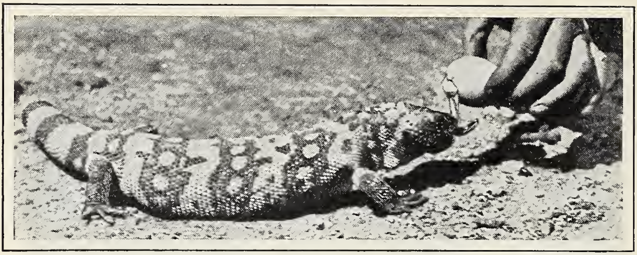
moment. Some people think that the animal is trying to harm them. They do not know that the tongue is very soft and sensitive, and is thought perhaps to be an organ of hearing as well as an organ of touch.

There are many adaptations for protection in this group. Some harmless snakes often resemble poisonous forms in color or in markings. Others may hiss and strike in a very convincing manner.

Turtles. These reptiles are protected by a shell developed partly from the skin, just as are the scales of other reptiles, and partly from the vertebræ (Fig. 145). The head, legs, and tail can be withdrawn under the shell when danger threatens. Some of our land turtles (the box turtles) have shells which are hinged across the middle of the underplate, so that the shell can be closed completely with the animal inside.

Turtles which live on land have distinct toes ending in claws. Those which spend all their time in the water have the legs modified into flippers for swimming.

The disposition of a turtle seems to be closely related to the amount of shell. The snapping turtle, for example, which has very little shell to protect it, is fierce and vicious, while the box turtle can hardly be persuaded to bite.



John Edwin Hogg

FIG. 146. The Gila monster is too much interested in the food here to be dangerous. What does this picture tell us of the food habits of this reptile?

These reptiles differ greatly in their choice of food. The snapping turtle and soft-shelled turtle feed on fish, frogs, crayfish, and water birds. Land turtles eat much vegetation, as well as many insects and worms.

Lizards. Lizards resemble certain of the amphibians in general appearance; but, unlike all but a few of the amphibians, they have scales. Unlike the snakes lizards have movable eyelids and ear openings. Among the lizards familiar in various parts of the United States are the skink, the swift, the chuckwalla, the horned toad, and the Gila (pronounced he'la) monster (Fig. 146).

Lizards are feared by many people almost as much as snakes. All are harmless, however, except the Gila monster, which lives chiefly in the desert regions of southwestern United States and is our only poisonous lizard. It seldom attacks man.

In certain parts of our country legless lizards are found. These animals move like snakes and closely resemble them in appearance, except that they have ear openings and movable eyelids.

Economic importance of reptiles. In general, man benefits from the feeding habits of reptiles because not only do they destroy few plants and animals of value to him but also they feed upon insects, squirrels, mice, and other animals harmful to crops. Some turtles, as well as a few species of lizards, especially the iguana, are prized for food. From the skins of alligators and crocodiles and certain snakes ornamental leathers are manufactured. In the United States the death toll from poisonous snakes and the Gila

monster is small. In some of the tropical countries, however, thousands of people die every year from snake bites. In India alone, in 1908, nearly twenty-two thousand people were killed by snakes, mostly by the cobra.

Self-test on Problem XII–D. **1.** The *largest* reptiles today are *larger* than the largest reptiles of previous ages.

2. The *dinosaurs* became extinct because they were unable to become adjusted sufficiently to a changing environment.

3. One characteristic of reptiles which marks an important advance over fish and amphibians is the possession of __(?)__ all of their lives instead of gills for part or all of their lives.

4. The shell of a turtle is a structure which is homologous to the __(?)__ of a snake.

5. *All* reptiles are hatched from eggs.

6. In general the snakes of the United States and Canada are more *valuable* than they are *harmful.*

7. Turtles show various *modifications* of structures which fit them for various environments.

8. A lizard can be distinguished from an amphibian usually by its *skin.*

9. A lizard, *like* a snake, has a *movable* eyelid.

10. Name the four kinds of poisonous snake and the one kind of poisonous lizard of the United States.

Problem XII–E · What are Some Adaptations of the Birds (Phylum Chordata, Class Aves) which Enable them to Compete successfully for Energy?

Birds are descended from reptiles. About seventy-five years ago a fossil feather and two fairly complete fossil skeletons of a strange creature were found embedded in the rock of the slate quarries of Bavaria. The creature, which was about the size of a crow, was apparently a bird. Yet it had a number of the characteristics of the reptiles (Fig. 147). It had three clawlike fingers on each wing, sharp cone-shaped teeth embedded in sockets in the strong jaws, a long tapering tail like a lizard, and some other reptilian[1] characteristics. It was, however, covered with feathers and had a number of other birdlike characteristics.

[1] *Reptilian* (rep til′i an): like a reptile or pertaining to a reptile.

A. M. N. H.

FIG. 147. Left, the hoatzin of the Amazon region; right, the most ancient known bird (*Archæopteryx*). Special Report: What are the characteristics and habits of the hoatzin (see encyclopedia under *hoactzin*)? What evidence can you give in support of the statement "The ancestors of all birds were reptiles"?

A careful study of these fossils convinced scientists that the creature was a bird rather than a reptile, and also that it was descended from the reptiles of a still earlier period. It is not thought likely, however, that the ancestors of this bird (*Archæopteryx*) were ancient flying reptiles (the pterodactyls). It seems somewhat more probable that the strange creature was a descendant of certain of the dinosaurs. It is even thought probable that this fossil bird represents the common ancestor of both the modern birds and the modern reptiles, since the birds and the reptiles of today are alike in several ways. Birds, for example, have scale-covered legs and feet, as do lizards and crocodiles. Moreover, most reptiles lay eggs, as do the birds.

Experiment 53. What are some of the characteristics of a living bird? You may use any kind of bird for this experiment. A robin or an English sparrow may be watched in your yard or on the school grounds.

A chicken, canary, or pigeon may be brought to school or observed at home. What is the shape of the body? Are the feathers which cover the body alike on all parts of the bird? How do you account for this fact? How does the bird use its wings? If you can observe it flying, try to describe the movements of the wings, and to show how these movements keep the bird moving through the air. For what purposes does it use the tail? Look closely at the feet. How many toes are there? Describe their shape and arrangement or make a sketch to show what you observe. Do all birds have feet like this?

Look closely at the beak. What shape is it? How does the bird use it in securing its food? Watch the bird drink. Make a sketch of the head and beak.

Are the eyes large or small as compared with the rest of the head? Do they seem to have the same parts as your eyes? If you can watch a bird closely, look for the third eyelid (nictitating membrane). Where is it attached? Find the nostril openings; the ears. Describe the location of these or put them on the sketch you have made of the head.

***Bird characteristics.** Birds are readily distinguished by the fact that they are the only animals that are covered with feathers. Like most other vertebrates every bird has two pairs of appendages, the front (anterior) pair of which is modified to serve as wings. Different orders of birds vary considerably, however, because of differences in the environments in which they live. Some birds, like the ostrich, have developed the ability to escape from their enemies by running rather than by flying. These have lost the use of their wings, which are now too small and weak to support the body. The penguin has its wings modified into paddles for swimming. (The internal structure of a bird is shown in Fig. 148.)

***Adaptations for life in the air.** Those birds that spend much of their time in the air need to be especially adapted for aërial life. The body is long and slender and therefore makes little friction with the air during flight. The bones, and the quills of the feathers, are hollow, or air-filled, and in the abdomen there are air spaces which connect with the lungs. The feathers form a very light, yet a very warm, covering.

Wings. The wing is really a modified foreleg, just as is the arm of a man. In fact, the structure of a bird's wing is much like that of a man's arm. The bones which have developed into fingers are much reduced in the birds, with the result that the wing is

lighter and affords a better surface for attachment of feathers. The wing feathers are long and strong, and overlap to make a

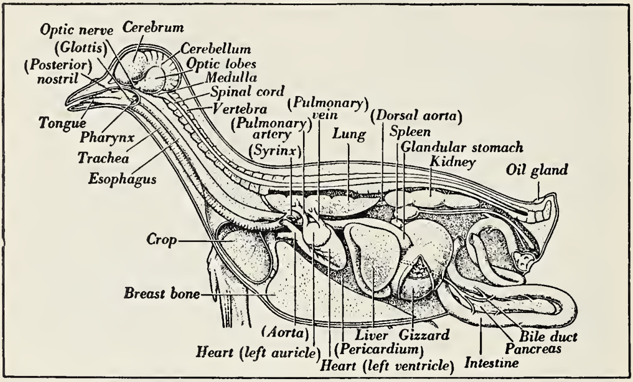


FIG. 148. Internal structure of a bird.[1] What internal structures do the bird and the frog (Fig. 140, p. 219) have in common?

broad surface to push against the air. On the upward stroke the feathers separate slightly and turn to allow the air to pass through, so that the bird does not push itself backward.

Birds that spend most of their time in the air have very long, powerful wings. The chimney swift is one of this sort. It is said to be able to spend as many as twelve hours continuously on the wing. Ground birds that fly only for short distances have short wings, which they may move very rapidly. Soaring birds, like the hawks, depend on the ascending air currents, which push against their long, broad wings and thus keep them up without effort. With birds such as geese, chickens, and turkeys the wings sometimes serve as weapons of defense.

Tail. The tail is usually used as a rudder in flight and as a brake for stopping. The wings are partly folded and the tail spread out when the bird wishes to alight. When the bird perches on a limb, its tail is used as a balance, serving the same purpose as the umbrella carried by a person who performs on a stretched wire

[1] From Meier and Meier's *Essentials of Biology.*

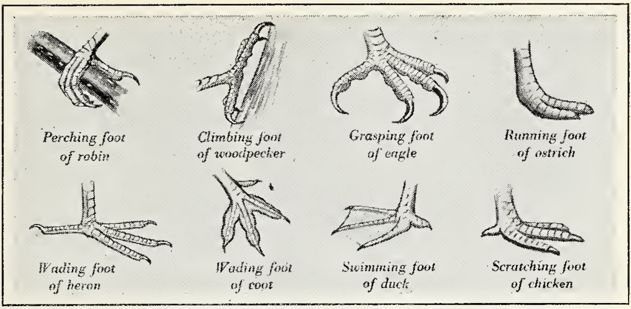


FIG. 149. Can you explain how these various adaptations of feet aid the birds in survival?

in a circus. In such birds as the woodpeckers and creepers the tail feathers end in stiffened tips which can be used to prop the bird on a tree trunk while it works.

Feet. Most of our birds have feet fitted for perching on trees or like supports. But different species can also use their feet for walking on the ground, for carrying prey, for fighting, and for various other purposes. Swimming birds have the toes wholly or partly webbed. Wading birds have a long ankle bone, and very long toes to support them in the soft mud. Birds of prey, like the eagle, have long curved talons[1] to hold their prey (Fig. 149).

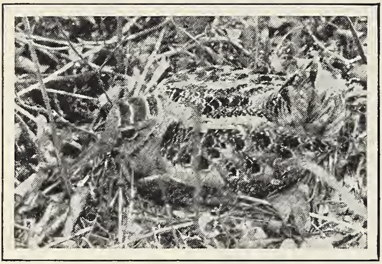
Usually a bird's foot has three toes in front and one behind. But in many of the woodpeckers there are two in front and two behind to help in climbing and in clinging to the bark of trees. In the birds of prey the outer front toe is readily movable, so that it may be turned to help the hind toe in holding a victim.

Feeding. We sometimes say that a person has the appetite of a bird, meaning to convey the idea that he eats very little. But if a person truly had the appetite of a bird, he would eat daily approximately his own weight in food. A very young robin eats two or three times its own weight every day.

Most of a bird's activity is concerned with feeding. From morning to night, except when it is resting sometimes in the hottest part of the day, the bird is constantly in search of food. It

[1] *Talon* (tal'un): the clawlike toenail of a bird.

requires a great amount of food to supply energy for its rapid flight. Then, too, a bird has a higher body temperature than any other animal (104° F. to 110° F.), and much of the food energy must be converted into heat energy to maintain this temperature.



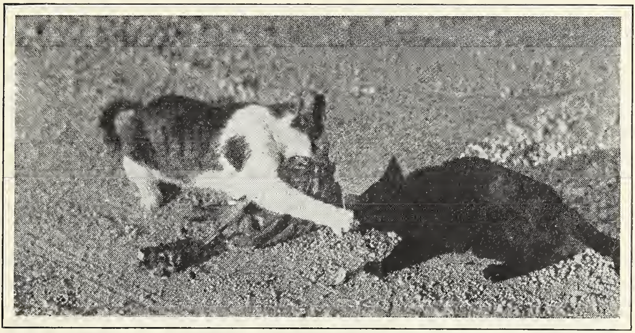
Lynwood M. Chace

Fig. 150. Self-test on Biological Principles: What biological principle is here illustrated by the woodcock on her nest?

It is largely because of their enormous appetites that birds are of so great benefit to man. A later chapter presents further facts concerning the ways in which birds help man.

Migration. The fact that birds possess wings and remarkable power of rapid and long-continued flight has enabled them to live more widely distributed over the world than any other sort of animal except man and probably the insects. If food fails or the climate becomes too severe, they can migrate to a more favorable environment. Some fish, a few insects, and certain mammals migrate. But no other animals can compare with the birds in this respect.

The question of why birds migrate is one which scientists cannot answer with any degree of certainty. It is clear that the insect feeders must go in winter to other regions where food is available. But why do they return to us in the spring? Some scientists say that this habit of migration is one left over from the past ages when great glaciers forced birds to move to warmer regions, though their tendency was to return north whenever the receding glaciers made their return possible. Then, too, if all birds remained all the year round in the south, there would not be room for nests and not sufficient food for all. Perhaps these facts have made them return farther north to build their nests and rear their young. Some scientists believe, moreover, that the return has some relation to reproduction. This theory will be discussed in Chapter XXX.



Beecher Beery

Fig. 151. Cats fighting over two birds they have caught. Does the cat "pay its way"? (Courtesy of National Association of Audubon Societies)

The birds of any region may be classified according to their habits in regard to migration. Some, the permanent residents, remain in one locality the year round. Summer residents return to us for their breeding seasons (Fig. 150). Winter residents come to us from colder regions in search of food and milder climate. Transients are those birds that remain with us for a short time on their way to northern summer homes or southern feeding grounds.

Bird enemies. Birds have many enemies. Snakes, squirrels, weasels, and many other animals feed upon the eggs and the young birds. Both old and young birds are the prey of other birds, such as hawks and owls. Birds which are large enough to be used as food by man are hunted ruthlessly. Insect parasites of various kinds also cause the death of countless birds and perhaps even of whole species. The common house cat, however, is probably the worst enemy of the smaller birds about our homes (Fig. 151). This animal sometimes hunts and kills as many birds as it can, even when it is well fed. The cat is often of small value compared with the birds it kills.

Self-test on Problem XII–E. **1.** The ancient ancestors of birds were __(?)__.

2. The birds are the only animals which are covered with __(?)__.

3. *None* of the bird ancestors of our modern birds could fly.

4. The bird's wing is similar in structure to the __(?)__ of a man.

5. State four different functions which the tails of birds may serve.

6. State four different functions which the feet of birds may serve.

7. Birds need much food energy as a source of both the *mechanical* energy of flight and __(?)__ energy.

8. *All* birds migrate.

9. Name eight or more bird enemies.

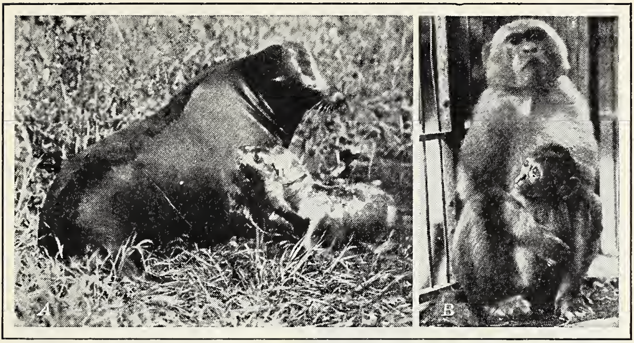
Problem XII–F · How are the Highest Animals (Phylum Chordata, Class Mammalia) Equipped to Compete for Energy?

Mammals are comparatively recent animals. A study of fossils found in ancient rocks convinces scientists that mammals appeared upon the earth perhaps one hundred fifty million, or even more, years ago. These earliest mammals, however, were unlike any now living. They were small and unimportant compared with the gigantic reptiles of that time. The mammals developed in size and importance as the Age of Reptiles waned, and have been the most important living things on the earth for the past fifty or sixty million years.

***Characteristics of mammals.** The mammals are the animals that we know best. Man, dogs, cats, horses, and cows belong to this group. They are called mammals because they have milk glands (mammary glands), that secrete food for the young. Other important characteristics are the following: (1) Their bodies are more or less covered with hair during at least part of their lives. (2) They breathe by lungs all their lives. (3) Their young resemble the parents in having the same general structures. (4) They are warm-blooded animals; that is, the body temperature remains the same throughout the winter and summer and is usually considerably above that of the habitat.

The young of all mammals except those of the lowest order are born alive. These simple mammals lay eggs, though the young are fed with milk, as are the young of all other mammals (Fig. 152).

Adaptations shown by limbs. Most of the mammals possess four limbs of practically equal length. These they use primarily for locomotion, but also for defense and for food-getting. There are



Newton H. Hartman

Fig. 152. *A*, northern California hair seal and day-old baby, Philadelphia zoo; *B*, mother monkey and baby. Special Reports: Discuss these animals (see "Suggestions for Effective Study," p. xv. Consult an encyclopedia or an advanced zoology textbook)

many interesting modifications of the limbs, and many uses to which the animal puts them (Fig. 153). Such animals as squirrels, opossums, and monkeys, which spend much of their time in trees,

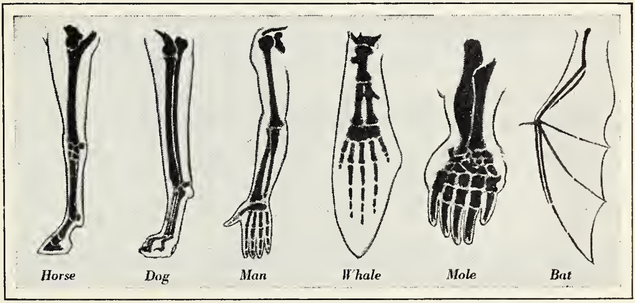
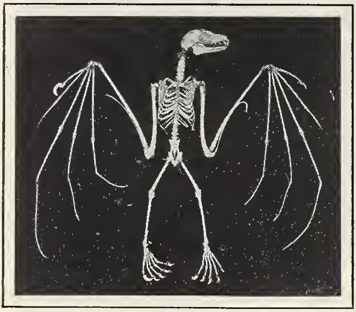


Fig. 153. Modified fore limbs of mammals. How do you explain the facts that (1) these limbs are so much alike and yet (2) they differ in some respects?

have feet adapted for climbing. Hoofed animals, like the horse and the deer, have very long slender legs which enable them to attain great speed. The carnivorous, or flesh-eating, animals, as

the cat and the lion, have padded feet on which they can approach their victims silently, and claws which can be extended to help in holding their prey. The mole (Fig. 158, p. 240) has its front feet greatly enlarged for digging.



General Biological Supply House

Fig. 154. What structures of the bat are homologous to those of man?

In some species the limbs are very different from one another. The very long hind legs of the kangaroo enable it to jump for considerable distances. In the bat the bones of the front limbs are greatly lengthened to support the membranes that form the wings (Fig. 154). Bats are the only mammals that are truly adapted for flying. The aquatic mammals, like the seal and the walrus, have the legs modified to form flippers, used in swimming.

The bony structure. Since the skeletons of all mammals are very similar, that of man may be studied as typical of the group (Fig. 155). The skeleton of man consists of two hundred six bones. These are of various shapes and structures. There are the long bones, such as those of the arm and the leg, which are hollow and filled with marrow. These bones are the levers which the muscles move to enable us to walk and to lift things. Then there are flat bones, such as those of the skull, the chief function of which is to protect internal organs.

Structure of bones. ***Experiment 54.*** What are the various parts of a bone? Secure from the butcher a leg bone of a cow or a sheep, with a joint. Remove the flesh from the bone and examine the surface of the bone carefully. Can you discover whether there is any sort of covering over the bone, under the flesh? Examine the joint. (The joint in a frog's leg from which the skin has been removed will serve instead of the cow or sheep joint.) What holds the two bones together? Where and how is this fastening attached to the bones? Rub your finger over the joint surfaces. Are they smooth or rough? Can you

see any advantage in this condition? With a meat saw, cut lengthwise through the end of the bone, making several lengthwise sections about two inches deep, so that when the sections are removed you can see clearly all the different structures inside the bone. Remove the sections by cutting the bone horizontally at the lower ends of the lengthwise cuts. You should be able to observe in these sections hard bone, spongy bone, yellow marrow, and white marrow. Draw a rough sketch locating these four structures and those which you discovered in the earlier parts of this experiment.

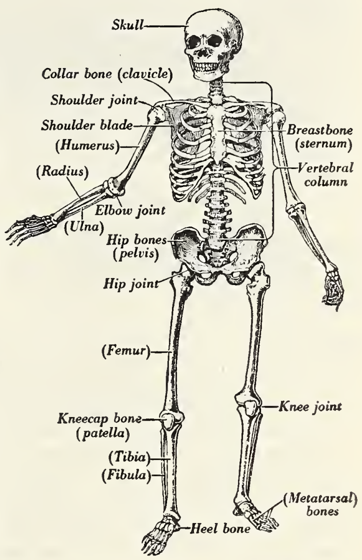


FIG. 155. What examples of the different types of joint (p. 238) can you locate here?

Experiment 55. What are the various kinds of joints? Secure from the butcher the head of a chicken or other fowl, a chicken leg with the knee joint, and the shoulder joint or hip joint of any fowl or animal. Boil the head until you can remove all the flesh from the bones. Examine the skull. Does it consist of one boxlike bone, or is it made up of several bones joined together? If so, how are these joined? In how many directions can you move the hip joint, the knee joint, and the ankle joint? Do these joints all permit the same kinds of motions? Summarize the results of your observations in a brief paragraph.

Bones are living tissue, just as are other softer parts of the body. We have evidence of this fact when we see that a bone grows as an animal increases in size, and that a broken bone can repair itself. Only living cells can perform these functions. A bone is made up of cells, with spaces between them which become filled with lime compounds, which make the bone hard (Fig. 156).

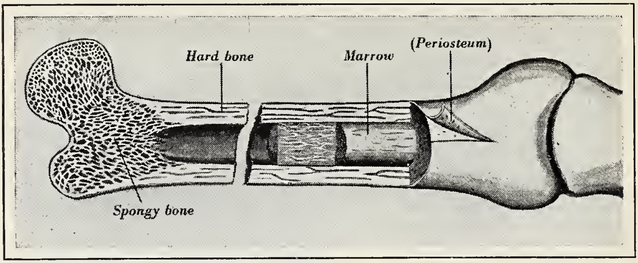


FIG. 156. Can you explain the function of all the structures seen here? (See text)

Bones are not entirely solid, but instead are quite spongy with numerous spaces where blood vessels and nerves can penetrate to all parts of the bone.

Experiment 56. What purposes do the animal and mineral matter in the bone serve? Secure two long bones, such as those found in the leg of a chicken. Place one in a weak solution of hydrochloric acid, to remove the mineral matter of the bone. Leave the bone in the liquid for about two days. Place the other in the flame of a Bunsen burner until the flame has consumed the animal matter of the bone. Examine the two specimens of bone. Has either specimen changed in color? Does either bend or break more easily than it did before it was changed by the acid or the fire? Answer with a brief paragraph the question asked at the beginning of this experiment.

The bones of the skull fit together in such a way that the joints are immovable, thus forming a box to inclose and protect the brain. In a very young animal these joints have not closed completely, leaving room for growth. Thus in a baby one finds the "soft spot" on the top of the head, which is often not entirely closed until the child is two years old. Other joints in the body are movable ones of three main types. The elbow is an example of a hinge joint. The shoulder is the best illustration of a ball-and-socket joint, which permits movement in any direction. The joint at the wrist is a sliding joint.

Protection and defense. Many mammals, in their claws, hoofs, teeth, tusks, and horns, have means of active defense against enemies. Others may escape by their speed. The antelope, for example, can run for short distances at the rate of sixty miles an

hour. Some animals which have no special organs of defense and no great speed of movement may depend upon their ability to remain concealed. Thus the mole remains safe in its underground burrow.

William S. Carlson

Fig. 157. Natural and artificial adaptations. What adaptations have the man and his dog team to protect them against the severe cold of this far-northern habitat?

The skin and the hairy covering of the mammals serve for protection both against attacking enemies and against unfavorable weather conditions and other factors. The covering of hair prevents the escape of too much heat (Fig. 157) and shields the surface of the body from blows or from bites. Most of the animals of cold climates have fur or wool. The hair of the porcupine has become modified to form spines, or quills. These spines may penetrate the skin around the mouth and nose of an attacker, causing great pain, and perhaps even death, as they work their way farther into the body. The whale, walrus, and seal, which live in very cold water, have a layer of fat, or blubber, just beneath the skin, which helps to prevent loss of heat. The armadillo has shell-like bands around its body. When it is attacked, it rolls into a ball and is completely protected.

Protective coloration. Often the color of an animal's coat blends with the surroundings in such a way as to conceal the animal from its enemies or to permit it to creep upon its prey unobserved. A rabbit motionless beside a clod of earth or a clump of grass, or a young deer motionless in the forest, is practically invisible until it moves. Zebras and tigers, living in the flickering light of the jungle, are striped. Polar bears are white like their environment. Some animals change color with the seasons. The arctic hare is gray-brown in the summer, but changes to white as the winter snows come.

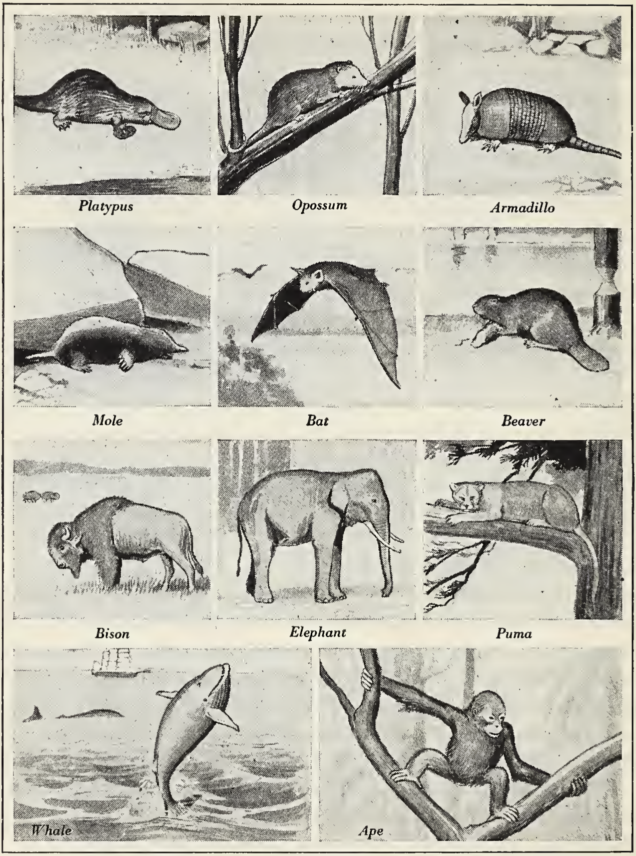


Fig. 158. Can you name one or more other mammals in each order here represented? What orders are not here represented?

Other protective adaptations. The severe conditions of winter demand special adaptations for protection. If the body temperature of mammals should be reduced to that of their surroundings, as is that of the frog, they would die. With the coming of

cold weather, therefore, many mammals develop heavy coats of fur or wool. Others, if their natural food is lacking in winter, may either hibernate to conserve energy or migrate to other locations where food can be found. Many mammals hibernate, but few migrate. The bear hibernates in severe winters when food is hard to get, but may remain active during mild winters. Squirrels and raccoons sleep during the coldest weather. Chipmunks and shrews store food and wake occasionally to eat.

Some important orders. Mammals differ greatly in their habits of life and in the form of their bodies. For these reasons scientists recognize several orders of the class Mammalia.

Sixteen orders of mammals are recognized today. These include, among the most familiar, the following (Fig. 158):

Egg-laying mammals (Monotremata): duckbill (platypus), echidna.
Pouched mammals (Marsupialia): kangaroo, opossum.
Partly toothless mammals (Edentata): sloth, anteater, armadillo.
Insect-eating mammals (Insectivora): mole, shrew.
Flying mammals (Chiroptera): bat.
Gnawing mammals (Rodentia): rat, squirrel, beaver.
Hoofed mammals[1] (Ungulata): horse, cow, deer, pig, moose.
Trunk-bearing mammals (Proboscidea): elephant.
Flesh-eating mammals (Carnivora): dog, cat, lion, seal, bear.
Water-inhabiting mammals (Cetacea): whale, porpoise.
Erect mammals (Primates): man, monkey, ape.

*Of the sixteen orders, the ungulates, or hoofed mammals, the carnivores, or flesh-eating mammals, and the rodents, or gnawing mammals, are of most importance to man. The ungulates and the carnivores will be discussed here. The rodents will be discussed in Chapter XXVI.

The ungulates, or hoofed mammals. This group includes both such game animals as the deer and antelope and such domesticated animals as the horse, cow, and pig. Their legs are specialized for rapid locomotion to help them to escape the flesh-eating animals that prey on them. They walk on the very tips of their toes, which are protected by a modified toenail, the hoof. The

[1] The hoofed mammals are commonly divided into two suborders: those with an even number of toes, as the camel, giraffe, and deer; those with an odd number of toes, as the horse, tapir, and rhinoceros.

horse has one completely developed toe on each foot; cows and deer have two; the rhinoceros has three.

Among the hoofed animals are those that have the peculiar habit of chewing the cud. That is, they gather grass or other vegetation as rapidly as they can and swallow it without chewing. Then they can retreat to a protected spot where enemies are not so likely to find them. The hastily swallowed balls of grass, the cuds, can be forced back into the mouth from the first stomach and thoroughly chewed. The cud-chewing animals (ruminants) include the members of the camel, deer, giraffe, and cattle families.

Man has domesticated more of the hoofed animals than of any other group. Horses have been bred both for racing and for heavy labor. Types of cattle have been developed for their milk-producing qualities, while other types have been selected for meat production. Cattle are used for plowing and other farm work in many parts of the world. Sheep furnish both meat and wool. The elephant, camel, llama, reindeer, and goat are among the beasts of burden used in various countries.

The carnivores, or flesh-eating mammals. The flesh-eating mammals have a very acute sense of smell. This enables them to track their prey. They also have sharp teeth and claws with which to seize and kill it. Of this group of animals, man has been able to domesticate chiefly the dog and the cat.

Self-test on Problem XII–F. 1. Mammals were of *great* importance during the time of the *great* dinosaurs.

2. Name four distinguishing characteristics of mammals.

3. *No* mammals lay eggs.

4. In general mammals need to produce *fewer* young than animals of other phyla because the young are usually guarded and fed by the parents.

5. The typical mammal has two *more* legs than the typical insect.

6. Bones consist *entirely* of living cells.

7. Select from the following words and phrases the one which does not belong with the rest: (1) blubber; (2) protective coloration; (3) hair; (4) wool; (5) teeth; (6) claws; (7) bones; (8) quills, or spines; (9) speed.

8. The mammals which are unable to endure cold winters must either __(?)__ or __(?)__ in order to survive.

9. Most domestic animals are *carnivorous*.

Self-test on Biological Principles. **1.** Explain how the facts about fish in Problem XII–B illustrate the balance of nature.

2. How does the adaptation for chewing the cud illustrate the principle "An organism must become adapted to its environment in order to survive"?

3. Cite evidence to illustrate these principles: (1) "To carry on better the functions of higher organisms cells are organized into tissues, tissues into organs, and organs into systems." (2) When the environment changes, an animal must either adjust itself to the change, migrate, or become extinct.

Self-test on Organization of Facts. What kinds of skeletons do representative plants and animals from the different phyla have? Can you arrange these different structures in order from simplest to most complex?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** List all the ways you can in which the fish is adapted for moving rapidly. What other adaptations enable fish to escape from enemies?

2. Frogs' and toads' eggs are spherical, black on top and white on the bottom. Can you explain why this is a desirable adaptation?

3. How does the metamorphosis of the frog resemble that of the butterfly? How does it differ?

4. Why would a snake have difficulty in moving on a smooth surface, such as a polished table top?

5. If you were to see an animal which you knew must be either a lizard or a salamander, how could you determine which it was? If you were to see an animal which looked like a snake, how could you be sure it was not a limbless lizard?

6. Can you name two examples of each of the following groups of birds for your own locality: summer residents, winter residents, transients?

7. How many mammals can you list in three minutes? Examine the list of mammals you made. Group together the ones that seem to be alike in some way. What are some of the facts that you used in making these groups?

Can you place each of the animals on your list in its proper order? (Consult a dictionary or an encyclopedia if you have difficulty.) Which of the orders listed are represented in your vicinity? Which of the orders listed are of most value to man for food? for furs? for beasts of burden? Which of these groups does most damage? How?

8. How are the legs of animals that live in trees modified? For what purposes can a squirrel or raccoon use its front feet? How is a flying squirrel adapted for gliding through the air? What other examples can you think of which show how mammals are fitted for the environment in which they live?

Marjorie Shanafelt

FIG. 159. Exercise on Scientific Attitudes: There is an old belief that there is a magic jewel in a toad's head. What can you learn about this ancient superstition? (Consult an encyclopedia.) Which of the scientific attitudes (pp. 12–13) relate to this old belief?

9. If one were to receive a severe blow on the head, what advantages would there be in having the skull constructed as it is rather than of one bone?

10. Compare the shell of a turtle with the exoskeleton of an insect.

11. Can you mention animals other than fish which are for sale in fish markets? To what phylum does each belong? You may need to review Unit III briefly before you can answer this last question.

Exercise on Scientific Attitudes. 1. One often hears it said that if a person finds it necessary to sleep on the ground where there are rattlesnakes, he will be safe if he puts a horsehair rope in a circle around his blankets, because a rattlesnake will not crawl over a horsehair rope. From the evidence in Fig. 143, *A* (p. 223), do you believe this statement to be true? Why? What scientific attitudes (pp. 12–13) are here illustrated by this belief and by your decision regarding it?

2. The tails of some of the lizards — for example, the glass snakes, or joint snakes and the swifts — break off readily. When attacked the lizard leaves its wriggling tail to hold the attention of its enemy while it escapes. We sometimes encounter the superstitious belief that the animal later returns for the tail, which joins itself to the body again. What scientific attitudes are illustrated by your unwillingness to believe this foolish story?

3. One frequently hears tales of a marvelous "hoop snake" which travels by grasping the end of its tail in its mouth and rolling along like a hoop. As it passes its prey or its enemy it is supposed to uncoil and thrust into its victim the sharp, poisonous spine on the end of its tail. Of course no such creature ever existed. How many scientific facts can

you state which would help to prove that the "hoop snake" could not exist? Which of the scientific attitudes (pp. 12–13) are illustrated by your unwillingness to believe in the existence of "hoop snakes"?

Exercise on Major Generalizations. Cite evidence from this chapter to illustrate this generalization, "The world is very old."

Exercise on Scientific Method. 1. Planning Experiments. One often hears that handling toads will cause warts on the hands. This belief is of course an absurd superstition (Fig. 159). Describe all the necessary steps of an experiment which, if performed, would *prove* that toads do not cause warts.

2. Making Inferences. *a.* If you have been boating or bathing in a lake or along the seashore and have observed the water plants, you have noted that they stretch upward toward the surface in much the same way that land plants stretch their branches and leaves upward. If, however, you have removed these plants from the water, you have found that their stalks were no longer able to hold up their leaves. Similarly, if you were to see a jellyfish on the surface of the ocean, you would observe its tentacles stretching almost straight down from its bell-shaped body. But if the jellyfish were washed upon the beach, you would find that it would lie on the sand in a flat mass. Many organisms, such as the water plants and the jellyfish, which live only in the water, have no supporting structures, though some of the plants become much longer than the tallest trees. Can you explain why they do not need such structures?

b. Remembering that the mineral matter in bone is largely lime, what do you infer the gas to be which rose from the bone immersed in the acid in Experiment 56? Test the accuracy of your inference by repeating the experiment and collecting the gas. Test the gas by the tests you learned in your general-science course or in the experiments in Chapter IV.

3. Making Hypotheses. What are some reasons which might account for the extinction of the giant sharks?

Project 15. To study a bird's wing. What is the bony structure of a bird's wing? The wing of a chicken or other large fowl should be used in this project. The wing bones of any bird which has been cooked for the table will serve very well if the wing has not been taken apart. Remove any bits of meat and scrub the bones with soapy water and a small brush. Take care not to lose any of the small bones of the lower part of the wing. When the bones are dry, fasten them in proper order to a piece of cardboard by putting a fine wire or thread through the cardboard and around the bones. Or you may fasten the bones together at the joints with a fine wire or with glue.

Project 16. To trace the migration routes of some of our local birds. Draw or trace an outline map of the Western Hemisphere. Consult Chapman's *Birds of Eastern North America* or a similar book, to learn the migration routes followed by various birds. Put lines on your map to represent the route of each bird you study. Do they return to us by the same route they follow south?

Project 17. To secure some frogs' eggs and to watch them develop into frogs. Bring some frogs' or toads' eggs into the laboratory. You will find them in almost any shallow water, about the middle of March or the first of April. Watch their development. Those of the spring peeper, or the tree frog, will prove extremely interesting, since they will complete their development before school is out. Be sure to have water plants and algæ in the water to furnish food. A hand lens or reading glass will help in your study of the developing eggs and later the tadpoles.

Project 18. To collect and classify turtles. The common turtles of our inland lakes and streams are the snapping turtle, pond turtle, musk turtle, soft-shelled turtle, and painted turtle. How many of these do you know at sight? Collect as many different kinds as you can find. Consult a reptile "key" or a college zoology for descriptions, and classify the turtles you have found. Do you find others not named above? Did you find any in the woods? After you have classified and studied them, return them to their natural habitats.

Special Reports. 1. What can you find out about the cod and halibut industries of New England and Newfoundland? canning salmon on the Pacific coast and in Alaska? the source and preparation of caviar?

2. How many different kinds of fresh, dried, and canned fish are for sale in your local markets and grocery stores?

3. Do flying fish really fly like birds? What is a lung fish? How is a climbing perch adapted for moving on land? (Consult an encyclopedia or an advanced textbook on zoology or ichthyology (the study of fishes).)

4. How do the Surinam toad and the marsupial frog bring forth their young alive? How does the obstetrical toad take care of the eggs? (Consult a college zoology or an encyclopedia.)

5. What are the characteristics and habits of the alligator and the crocodile? of the chameleon?

6. Where are the poison fangs of the Gila monster, and how does the animal use them in fighting? (Consult a book on reptiles or an encyclopedia.)

7. Who was James Audubon? For what purposes are Audubon societies established?

8. What mammals other than those named in this chapter hibernate during all or part of the winter? What mammals store food for winter use? What mammals build nests or similar homes? Migration: The fur seal and the reindeer are among the mammals that migrate. Find facts concerning their habits. The lemmings of Scandinavia have very unusual habits of migration. Report on this migration.

9. What carnivorous mammals are injurious to domestic animals in some parts of North America?

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UNIT IV · *Structures and Processes Concerned with Securing and Using Food Energy*

PROBLEMS DISCUSSED IN THIS UNIT

Through a microscope one watches paramecia swimming rapidly across the field of vision. Through the window one sees a robin hopping about and stopping every few seconds with his head on one side as if to listen. The paramecia and the robin are engaged in the most important activity of all living things, that of food-getting. Whether an organism survives or not depends largely upon its success in securing a sufficient supply of energy in the form of food. Of equal importance with getting food, however, is being able to use the food after it has been secured.

Unit I discussed the seriousness of the constant struggle of every organism for food. Unit II presented the ways in which green plants make and store all the food which is available to all other living things. Unit III briefly described the various classes of organisms, and their adaptations which enable them to compete with one another for the limited supply of food energy which the green plants provide. The unit that follows will present the ways in which the various organisms are adapted for securing food energy and for using it in their bodies. The major problems which the unit discusses are these:

How do different plants and animals secure food?
How is food prepared for use by living cells?
How do plants and animals "breathe"?
How do living cells secure energy and get rid of waste products?
What is a gland, and how are glands related to the food problem?

Chapter XIII · How Organisms Meet the Food Problem

Questions this Chapter Answers

What different kinds of structures aid living things in securing food?
How is division of labor illustrated in food-getting?
How did the food-getting problem of ancient man differ from that of modern man?
What are the classes of foods?
In what respects is the body like an engine?
What specific purposes do the different classes of foods serve?
What is the relation of water to diet?

Problem XIII–A · How are Typical Plants and Some of the Simpler Animals Equipped to Secure the Food they Need?

The struggle for energy by plants. As has already been explained (p. 19), plants are classed as independent or dependent on the basis of whether or not they are able to make their own food. Nearly all the higher plants are independent. There are, however, a few, such as the Indian pipe (Fig. 160) and the coral root, which lack chlorophyll and hence are dependent. Most of the other dependent plants are simple plants, chiefly fungi, and are found in the lowest phylum.

Fig. 160. The Indian pipe is a saprophytic flowering plant. Can you explain the meaning of this statement? (See Glossary)

The simplest of these plants, such as the bacteria, have no special structures for obtaining food. Hence they take dissolved food materials by osmosis through the cell walls at any place. More complex saprophytes, such as some of the molds and the mushrooms, have rootlike structures which absorb food from the

General Biological Supply House

FIG. 161. Two carnivorous plants: *A*, pitcher plants; *B*, Venus's flytrap. These plants are unable to secure sufficient nitrogen from the soil for their needs. They must therefore supplement[1] the soil nitrogen by being able to capture insects. **Special Reports:** How do the pitcher plant, Venus's flytrap, and the sundew capture insects? (Consult an encyclopedia or an advanced botany textbook)

organic material upon which the plant lives. The parasitic flowering plants, such as mistletoe (Fig. 9, p. 19) and dodder, push their roots through the bark of the host into the phloëm cells, from which they take the food materials they need (Fig. 161).

The struggle for energy by animals. One of the important differences between plants and animals is concerned with the ways of securing food. The green plants make their own food by photosynthesis. Animals, however, can use only organic food, that is, the bodies or the products of other organisms. This difference between animals and plants is not without exceptions, because dependent plants, like animals, use only organic food. There are also many other exceptions to this difference (Fig. 162).

When it is recalled that the general term *animal* includes all organisms from the microscopic one-celled protozoans to the great mammals, it is easy to understand the wide variety of ways in which the different kinds of animals secure food energy. Most

[1] *Supplement* (sup′le ment): to add to something or supply what is lacking.

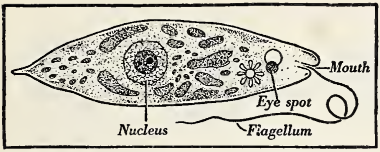
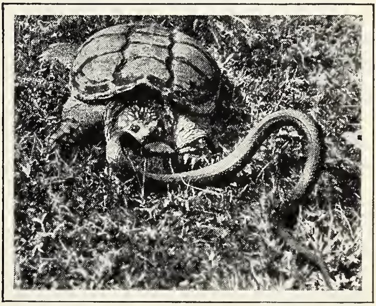


FIG. 162. *Euglena* has chlorophyll by which it makes part of its food by photosynthesis, like green plants. It also has a "mouth" with which it engulfs organic matter, like an animal. It also absorbs through its cell wall products of the decay of organic matter, like a saprophytic plant. What advantages does this organism derive from these varied ways of securing energy?

of the animals, even the simplest, have to seek for and capture their food. To survive they must possess unique structures and other means for doing this. Otherwise they and their kind would vanish from the earth. They must be able to grasp their plant food or to seize their living animal prey with teeth, claws, or other structures (Fig. 163). Or, like the honeybee or the mosquito, they must be able to penetrate to the portion of an animal or a plant where the food they need exists. A few additional examples will be given to illustrate how typical animals secure food.



Lynwood M. Chace

FIG. 163. A snapping turtle seizes a water snake. What biological principle is illustrated in this picture?

Food-getting by *Amœba*. The most primitive method of securing food is by osmosis. This method serves some of the protozoans and probably most of the parasites living in the blood corpuscles, food tubes, or other parts of their host animals, including man. Animals that feed by osmosis need not have teeth or even a mouth for securing their food, since their bodies are bathed in nutrient[1] liquids.

If one watches an amœba through a microscope, one may see how an animal without definite form and without specialized

[1] *Nutrient* (nu'tre ent): having to do with nourishment.

FIG. 164. An amœba ingests a resting euglena (cyst). Can you explain these pictures?

structures ingests[1] its food. If an amœba comes in contact with a grain of sand or something else which it cannot eat, it crawls away from the object. If, however, the particle encountered by the amœba is something which it can eat, it immediately begins to eat the particle. First the amœba puts forth a projection on each side of the food particle (Fig. 164). It pushes these projections farther and farther around the particle until the projections meet. The food particle with a little of the water around it is then completely surrounded by the protoplasm of the amœba. Thus, since the amœba has no cell wall, any part of the body which comes in contact with food may act as a mouth in ingesting the various simple animals or other organic bodies.

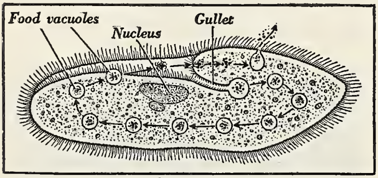


FIG. 165. Do the cilia of *Paramecium* have any function other than the ingestion of food?

Food-getting by *Paramecium*. *Paramecium* has a definite portion of its body which is concerned only with securing food. In this respect, therefore, *Paramecium* is a more highly specialized animal than *Amœba*. Along one side of *Paramecium* is a funnel-shaped groove which ends in a sort of "mouth." The groove is lined with hairlike cilia. The beating of these cilia make currents of water which carry particles of food to the mouth, or gullet (Fig. 165). The protoplasm at this point separates to admit food, and forms a food vacuole, which resembles a bubble in water. You may find many food vacuoles in the body of *Paramecium*.

[1] *Ingest* (in jest'): to take food into the body, to eat. *Ingestion* (in jes'chun): the act of ingesting or eating.

Food-getting by sponges. In its food-getting, the sponge illustrates true division of labor, since certain cells ingest food for the entire animal. Water bearing organic food particles is caused to circulate through the cavities in the animal by hairlike structures (flagella) on the lining cells. These cells then capture the food particles in much the same way as does an amœba.

Food-getting by *Hydra*. A hydra illustrates true division of labor, since it has certain structures which are concerned with capturing food. The tentacles are its food-capturing organs (Fig. 166). These tentacles are equipped with stinging cells (nematocysts) with which it paralyzes[1] its prey. The prey consists almost entirely of small water animals, such as crustaceans or insect larvæ. If you observe a hydra placed in a small amount of water containing water fleas or other small animals, you may see how it gets its food. A water flea swimming actively about presently strikes a tentacle of the hydra. It stops at once and is unable to go on. At the moment of contact the stinging cells discharge tiny poisoned darts into the body of the water flea. The paralyzed animal is then pushed by the tentacles into the hydra's mouth.

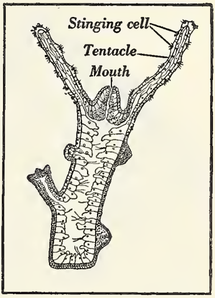


FIG. 166. *Hydra*, showing its food-getting structures. The stinging cells (nematocysts) are scattered over most of the hydra's body. Those not on the tentacles cannot serve in capturing food. What purpose might they serve?

Food-getting by the earthworm. The earthworm may be said to eat its way through the ground, swallowing sand and dirt along with decaying leaves and other organic materials. The animal digests useful parts, that is, the organic material. It deposits the undigested parts in the form of "castings" on the surface of the ground near the burrow.

Food-getting by the snail. The snail has a horny jaw for scraping up and holding the vegetable food which it eats. In the mouth there is a ribbonlike tongue covered with tiny teeth (Fig. 167). The snail runs this tongue over its food material and scrapes off tiny particles. If very numerous, snails or their relatives the

[1] *Paralyze* (par'a lize): to make unable to move.

slugs may become pests by eating the leaves of garden plants. But these same eating habits make them very useful in an aquarium. They will keep the glass free of algæ that otherwise would collect there.

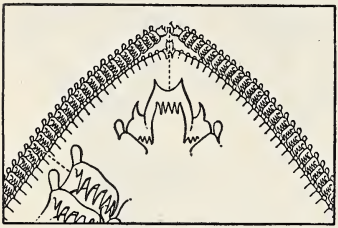


FIG. 167. Part of the tongue and teeth of a snail. The central tooth and two teeth at the side are enlarged. Why is the snail served better by having many such teeth than it would be by having a few scattered here and there on its tongue?

***Summary.** The ways in which plants and animals secure food have here been illustrated by a typical organism from each of several phyla described in Unit III. The food-getting habits of the flatworms and the roundworms were described in Chapter X. It will be seen that in general the more complex the animal, the more complex its method of obtaining food. Moreover, the stages of increasing complexity of methods of food-getting in general are found to parallel increasing complexity of structure. The stages and the structures illustrated are these:

1. No specialized structures; food can be taken in at any part of the animal. (*Amœba*, phylum Protozoa.)
2. No food-getting organs, but a definite point of entrance for the food and rudimentary structures for securing food and directing it into a rudimentary mouth. (*Paramecium*, phylum Protozoa.)
3. The beginnings of division of labor, with certain cells collecting the food for the entire animal. (Sponge, phylum Porifera.)
4. Simple organs used in securing food and putting it into a rudimentary mouth. (*Hydra*, phylum Cœlenterata.)
5. A mouth actually used in securing food. (Earthworm, phylum Annelida.)
6. A mouth equipped with teeth. (Snail, phylum Mollusca.)

All the animals discussed in the remainder of this chapter are equipped with complex food-getting structures. Differences in the ways of food-getting are illustrated both with representatives of the two phyla of higher animals, the arthropods and the chordates, and with typical animals within these phyla.

Self-test on Problem XIII–A. 1. *Independent* plants secure their food by the process of *photosynthesis.*

2. *Few* of the higher plants make their own food.

3. *All* parasites make *all* of their own food.

4. *All saprophytes* make *all* of their own food.

5. The lowest animal parasites secure their food by *symbiosis.*

6. Choose the best ending to the following statement: One important difference between animals and plants is that (1) all animals have legs; (2) all plants make their own food; (3) no animal is able to make its own food, though green plants can do so; (4) no plant captures living food as do many of the animals; (5) no plants can live on organic food, while all animals can live only on organic food.

7. The lowest animal which illustrates true division of labor in food-getting is the __(?)__.

8. Name and illustrate the various stages of increasing complexity of methods of food-getting, as illustrated in this problem.

Problem XIII–B · How are the Highest Invertebrates and the Chordates Equipped to Secure Food?

Food-getting of the crayfish. The crayfish eats plants and small animals, including other crayfish. It also eats dead fish or other refuse. The large claws or pincers are used to catch the food or to hold it and tear it. The smaller pincers on the first two pairs of legs help to hold the food within reach of the mouth. There are six pairs of mouth parts that hold the food and grind it, working sidewise. Three pairs of these are like small feet (maxillipeds). Two pairs (maxillæ) are flat and scooplike. And one pair (mandibles) is hard and toothed for cutting the food.

***Food-getting of insects.** Insects have a variety of ways of securing food. Some live on bits of plant or animal tissue which they chew and swallow. Others suck the juices from living plants or animals. Still others use for their food the nectar produced by flowers. It is plain that no single pattern of mouth would serve all these purposes equally well. We find, therefore, that the mouth parts of an insect are modified according to the kind of food it eats (Fig. 168).

Cornelia Clarke

FIG. 168. Mouth parts are adapted to food habits. Which of these insects has mouth parts most like those of the grasshopper (Fig. 125, p. 196)?

The honeybee has a combination of types of mouth parts. There is one part fitted for sucking up the nectar of the flowers it visits, and other parts fitted for cutting and shaping wax to form the honeycomb (Fig. 168, *A*).

The butterfly and the moth live on the nectar found in flowers like the morning-glory and clover. Many of these flowers have very deep cups into which the butterfly's or the moth's large wings will not permit it to crawl. It, therefore, has a very long tubelike mouth, by means of which it reaches its food. This tube is coiled up under the head of the insect when not in use (Fig. 168, *B*).

The mosquito is a good example of an insect that lives on the

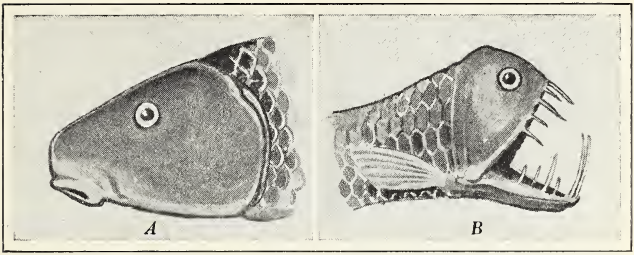


Fig. 169. Mouths are adapted to food habits. Exercise on Scientific Method (Making Inferences): One of these fish secures its food from the river bottom. The other preys upon fish which can swim rapidly. Can you decide from the mouth structures which fish answers each description?

life juices of plants and animals. It has a sharp needlelike beak with which it pierces the body of its victim (Fig. 168, *C*). The juices are then forced up through this hollow beak when a partial vacuum is produced by the action of the stomach.

The beetle (Fig. 168, *D*) has a mouth fitted for chewing grass and other vegetation. One pair of hard-toothed jaws (mandibles) move from side to side, like those of the crayfish, instead of up and down as ours do. These serve to bite off blades of grass. A second pair of jaws (maxillæ) helps to hold the food and cut it. An upper lip (labrum) and a lower lip (labium) aid in holding the food. Attached to the second jaws and to the lower lip are two pairs of fingerlike organs (palpi) which may be used in finding food.

Food-getting of a fish. ***Experiment 57.*** How does a fish obtain food? Examine the head of a goldfish, perch, or other fish. Where is the mouth? What advantage is there in having it in this position? Do all fish have mouths like this? Open the mouth. Does the fish have any teeth? If so, where? Does a fish chew its food? Does it need teeth for any other purpose? Summarize your observations.

The kind of food a fish eats depends upon both the age and the species of the fish. Young fish or such small fish as minnows eat small water animals of many sorts. Certain minnows are "top feeders," catching insects that light on the surface of the water. Other fish are "bottom feeders," searching about in the mud or sand for crustaceans, mollusks, or worms. Such are the sea bass,

the suckers, the mud cats, and the catfish of our rivers. Still other fish prey upon smaller fish. These fish — for example, the bass and the crappie — have large mouths and strong teeth to seize and hold their victims. Teeth are found along the edges of the jaws, on the roof of the mouth, and even on the tongue. Some fish, like the trout, are at times "top feeders," at other times "bottom feeders," and at still other times fish of prey. Fish swallow their food whole (Fig. 169).

FIG. 170. What other animals would you expect to capture insects by a method similar to the one shown here for the frog?

Food-getting of an amphibian. The tongue of a frog is covered with a glue-like substance to which its prey sticks (Fig. 170). The frog uses its front feet to push larger prey into its mouth. Cone-shaped teeth, in the upper jaw and in two bones in the roof of the mouth, are used for holding the food, but are not used for chewing. The frog eats nothing but living animals such as insects, worms, and smaller frogs. It will starve to death when surrounded by dead flies or dead worms, but will snap up any small moving object, even a marble or a piece of cloth. It swallows its prey whole. If it swallows a moving object that does not prove to be food, the frog can cast out the object from its mouth.

Food-getting of a reptile. Our common snakes capture their food by a quick movement of the head and swallow it whole. The teeth are small and sharp and point toward the throat to aid in keeping the victim from escaping. Certain snakes, like the gopher snake and the boa constrictor, capture their prey by winding their bodies about it and crushing it to death. In the poisonous snakes (Fig. 171) the fangs are an adaptation for getting food and for defense. The poison is injected into the prey to render it helpless.

Food-getting of a bird. For all birds except the birds of prey, like the hawk and the eagle, the beak is the only means of securing food. We can tell much about the habits of a bird, and especially

about its food, by examining its beak (Fig. 172). The strong cone-shaped beak of the sparrows is well fitted for crushing weed seeds but less useful for catching insects. The slender pointed beaks of the nuthatches and warblers are much better fitted for securing insects from under bits of bark or from flowers. The owl and the hawk have hooked beaks, well adapted for tearing apart their prey. It takes a very strong bill like the woodpecker's to drill holes in wood so that the bird may locate the boring insects which form its chief food.

New York Zoological Society

Fig. 171. The fangs of a rattlesnake. The smaller teeth do not show in this picture. Do you think that they point toward the throat or toward the front of the mouth? Explain

A bird swallows its food whole. No present-day bird has teeth set in its jaws, as did its ancient reptile ancestors. Some kinds of beaks, however, have toothed edges which help the bird in grasping and holding food.

Food-getting of mammals. You have probably already noticed that the teeth of a dog and those of a horse are very different.

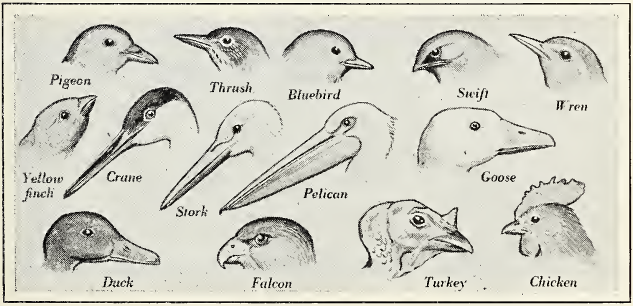


Fig. 172. Can you decide from the appearance of the beak what kind of food each bird probably eats? Check your inferences by consulting a "bird book"

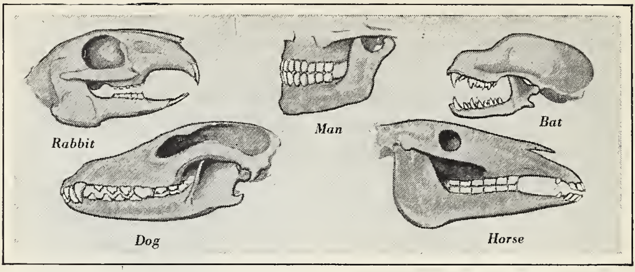


FIG. 173. Can you explain the relation of food habits to the structure of teeth in these animals?

The kind of teeth an animal has is closely related to the kind of food it eats. The dog, like the cat, the wolf, and the tiger, has long sharp teeth, called canine teeth or canines, on each side near the front of the jaw, fitted for catching and killing the animals it preys upon.

The teeth of the horse are very different from those of the dog. The front teeth, or incisors, are long and broad, fitted for cutting off grass or other vegetation. The molars, or back teeth, are flat and heavy for grinding food that otherwise would be hard to digest. There is a space between the molars and the front teeth and into this space the bridle bit is placed.

Insect-eating mammals, like the bat, have many small sharp teeth for crushing their food. The gnawing animals, like rats and mice, rabbits and beavers, have chisel-like incisors that grow continuously and wear down to keep a sharp cutting edge. Animals which, like man, eat all sorts of food (omnivorous animals) have incisors for biting off pieces of food, canines modified to help in biting, and molars for grinding (Fig. 173).

Self-test on Problem XIII–B. **1.** The mouth parts of *few animals* vary with the kinds of food they eat.

2. Match each phrase under B with one or two phrases under A.

A	B
Salmon and bass	Animals that crush their food before swallowing it whole
All vertebrates	Having only sucking mouth parts
Black snake and gopher snake	

All chordates	Biting and chewing mouth parts
Insects which live on the blood of living animals	Claws to hold food
Leaf-eating insects	Animals which swallow their food whole immediately after capturing it
Honeybees and wasps	Animals which use their feet in capturing their prey
Tapeworms and liver flukes	
Hawks and eagles	
All arthropods	
Protozoa	

Problem XIII–C · What are Some Problems of Man in Relation to Food?

Ancient and modern food problems. Primitive man spent much of his time in search of energy in the form of food. Having no means of storing or preserving foods, he was forced to roam the forests in search of fruits, nuts, edible plants, and such animals as he could kill. Always he must be alert[1] lest he himself become the food of some other animal. If food happened to be scarce, he was forced to go without until he could find a meal, however long a time it might take him to find it. If he happened to find food in plenty, he made the most of his good fortune by gorging himself with a far greater quantity than present-day man would attempt to eat at one meal.

Contrast primitive man's problem of securing food with that of modern man. Ships bring us staple foods and delicacies from every corner of the world. In our gardens, orchards, and farms we grow all sorts of food crops most of which have been introduced from other parts of the world to supplement our own native plants. Modern means of transportation and refrigeration make it possible for us to obtain fresh fruits and vegetables from foreign lands, as well as from all parts of our own country, at all seasons of the year. Fresh foods are supplemented with canned meats, fish, fruit, and vegetables in great variety.

Classes of foods. It would not be strange if we were to believe that in our markets we could find almost any kind of food which anybody might care to eat. We should be forced to change this idea, however, upon visiting foreign countries. There we might

[1] *Alert* (a lert′): keenly watchful.

have difficulty in finding our familiar foods. We should find instead strange and novel things to eat (Fig. 174).

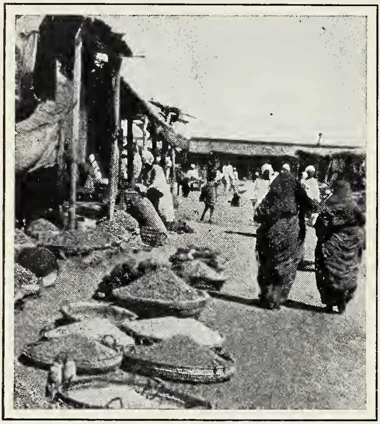


FIG. 174. An Arabian food market. Can you suggest what some of these foods may be?

Such experiences make it seem that there are an endless number of foods. This is true, however, in only a very limited sense. There is indeed a wide variety of different food plants. Of some the stems are eaten; of others, the roots, leaves, buds, flowers, seeds, or fruits. Also there are many animals and their products which may be used as foods. Yet all these various foods may be placed in two groups, those which yield energy and those which do not.

*The energy foods are of three classes: carbohydrates, proteins, and fats. All are essential to life. Of the foods which do not yield energy, some are necessary to life, and some are not. Those that are necessary to life include vitamins, various mineral salts, and water. The nonessential, or accessory, foods include the food flavors, the condiments (such as mustard, pepper, and similar substances), and the stimulants (such as coffee, tea, and cocoa). All the things we eat as foods are included in these classes of food substances.

***Why we need food.** Food furnishes all the materials for building protoplasm and supplies energy for all its activities. All the processes which have to do with the use of food in the cell are called *metabolism*. Metabolism includes the release of energy, the building of protoplasm, and the elimination of wastes from the cell.

If a person were to try to remain entirely inactive, he would nevertheless use up considerable energy. His life processes, such

as breathing, digestion, and blood circulation, would of course continue. These processes would consume energy, not only for necessary movement but also for growth and for replacement of worn-out cells. In the process of eating to restore needed energy he would use additional energy. Still more energy would be necessary if he did any work at all. If he were an office worker, he would use less than twice as much energy in doing his daily work as he would in lying as nearly motionless as possible. If he did light muscular work, he would use only about three times as much energy as if he lay motionless all day. If he were engaged in hard labor, he would use nearly ten times as much. Food is needed to supply this energy. If he ate nothing, the reserve energy stored as sugar and fat in the body would first be consumed. Then the protoplasm of the body tissues themselves would be used up as fuel.

The energy which our bodies require can be accurately measured in Calories. A *Calorie* is the quantity of heat energy required to raise the temperature of one kilogram of water (1000 grams) through one degree centigrade[1]. Thus the average city dweller needs about 2500 Calories per day of energy in performing all his life activities, while the man at hard labor requires from 3500 to 5000 Calories. This last amount of energy would be equivalent to that required in lifting a ton nearly one and a half miles.

The body like an engine. In an automobile the gasoline is the potential, or stored, energy. When the engine is started, this potential energy is converted into three forms: (1) the chemical energy from the various chemical changes; (2) the mechanical energy of the moving parts; (3) heat energy, from both the chemical changes of combustion and the friction in the moving parts. The human body can be roughly compared to the gasoline engine. In the body the food is the potential, or stored, energy. It is fuel, just as gasoline and coal are fuel. It is burned in the cells of the body as gasoline is burned in the engine. The food energy is transformed into the same three forms of energy into which the gasoline was transformed in the automobile engine: (1) the

[1] This is the great Calorie. The small calorie, used in physics, is the quantity of heat energy required to raise one gram of water through one degree centigrade.

chemical energy of the processes of digestion, respiration, and all the other bodily processes; (2) the mechanical energy of movement; (3) heat energy. The heat energy here, as in the gasoline engine, results from both the combustion of fuel and the friction of moving muscles. Like the moving parts of any machine the muscles of the body are not very efficient. Much more energy is put into them than is transformed into useful work. Even the heart, which is perhaps the most efficient of all the organs of the body, transforms in its movements only about 20 per cent of the energy which goes to it. Most of the energy which is not transformed by muscles into useful movements is transformed into heat. In the body, as in the engine, and whenever any sort of fuel is burned, the chief products of combustion are carbon dioxide and water.

Self-test on Problem XIII–C. **1.** There are *no* foods which do not yield energy.

2. The three types of energy foods are __(?)__, __(?)__, and __(?)__.

3. The process which includes the use of food by the cells and the release of energy is called *photosynthesis*.

4. We use *no* energy when we remain quiet.

5. Heat energy is measured in *degrees*.

6. Food energy is transformed in the body into __(?)__ energy, __(?)__ energy, and __(?)__ energy.

7. Whenever fuel, such as coal in an engine or food in a living cell, is burned, or oxidized, two waste products are always formed. These are __(?)__ and __(?)__.

Problem XIII–D · What are Some Important Facts about the Energy Foods?

The energy foods. As has been already stated, every living thing is using energy every instant of its existence, even when it is as inactive as possible. Of the food materials mentioned earlier in this chapter, only three can serve as fuel in the body. These are carbohydrates, proteins, and fats. Carbohydrates and proteins furnish each 4.1 Calories of heat energy per gram, and fat 9.3 Calories per gram (Fig. 175). If eating were only a problem of

securing the needed amount of fuel, then any one of these three foods would serve without the others. But each has certain functions or advantages making it necessary to eat all three.

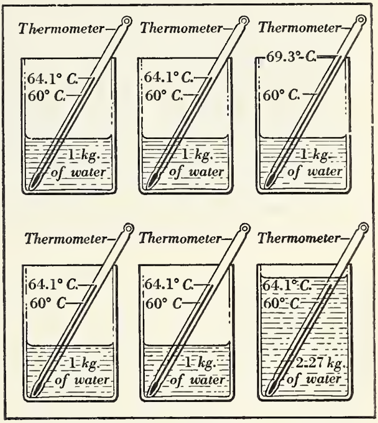


FIG. 175. The three upper vessels represent the fact that one gram of either carbohydrates or proteins furnishes enough Calories of heat energy to raise the temperature of one kilogram of water 4.1° C., and that one gram of fat supplies enough Calories of heat energy to raise the temperature of one kilogram of water 9.3° C. Can you explain what the three lower figures represent?

Most of the things we eat contain more than one of the foods which supply energy. It is difficult to find substances which contain only one of the three nutrients. Usually foods contain some of each one of the three, — carbohydrates, fats, and proteins, — though the proportions differ greatly. It is easy to test for these nutrient substances.

Experiment 58. How may one determine whether a given food contains sugar? To find a test for a given substance it is necessary to have both a test substance and a control. In this experiment take a sugar, such as glucose, for the test substance and another substance which contains no sugar at all, such as white of egg, for the control. Put into one test tube a little of the glucose and into another a little of the egg white. Add water; then heat equally both test tubes. Add to each a mixture of Fehling's solutions A and B. What do you observe in each test tube? Any substance containing sugar will act like the glucose in this test when treated in this way. Make the test, therefore, of a number of foods, such as candy, honey, beans, bread, meat, and so on.

Experiment 59. How may one determine whether a given substance contains protein? For the test substance in this case choose white of egg, which contains a considerable amount of protein, and for the control use sugar. Boil a sample of each in a little water; then add a

small amount of nitric acid. After a few moments add a little ammonium hydroxide, *a drop or so at a time.* What do you observe in each test tube? The effect you observe indicates the presence of protein. Make the protein test now of a number of food substances, such as milk, meat, honey, beans, bread, and so on.

Experiment 60. How may one determine whether a given substance contains fat? Use for the test substance something which you know contains fat, such as lard or butter. Use for the control something which you know does not contain fat, such as a cube of sugar. Rub each sample upon a sheet of paper; then hold the paper toward the light. What happens with each sample? Test various food substances for fat.

For the starch test see photosynthesis (Experiment 12, p. 78).

Record the results of these tests as in the following table:

Food Tests

Name of Food	Starch	Sugar	Protein	Fat
Cornstarch	+	?	–	?
White of egg	?	–	+	?
Sugar	?	+	?	–
Bread	?	?	?	?
——	?	?	?	?
——	?	?	?	?

Add the names of the other foods which you tested, placing in each column a + if the food contained the substance indicated and a – if it did not. Compare your results with those obtained by other members of the class. In all cases where various members disagree, the tests should be carefully repeated until you are all sure which are the correct answers.

Exercise on scientific method (using controls and evaluating procedures). Explain the purpose of the controls in these experiments. What was the purpose of repeating the experiments when the different members of the class disagreed in their results? If all the members of the class agreed in the case of any given result, should you know positively that that result was correct? Explain.

Experiment 61. What kinds of foods are stored in seeds? Test beans, corn, peas, peanuts, walnuts, or any other seeds to determine what kinds of energy foods are stored in the seeds. Make a table which summarizes your findings.

Experiment 62. What kinds of foods are stored in roots? Test such fleshy roots as beets, turnips, carrots, radishes, and parsnips to determine which of the energy foods they contain. Make a table to record your observations. Summarize your conclusions in one or two sentences

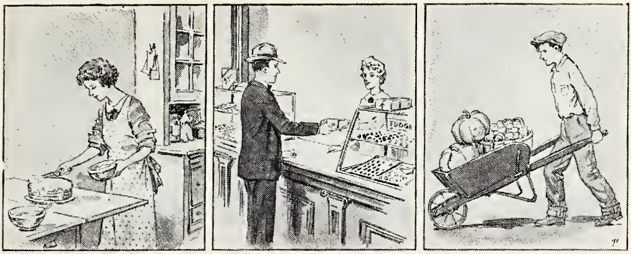


FIG. 176. What carbohydrate foods are shown in these pictures? Explain how each comes directly or indirectly from plants

***Values of the different classes of foods.** *Carbohydrates.* The carbohydrate foods — starches and sugars — are cheaper than fats and proteins. They are, moreover, more completely absorbed by the body. Common carbohydrate foods are potatoes, bread, and sugar. All carbohydrate foods come directly or indirectly from plants (Fig. 176). Sugars are a quick source of energy. For this reason athletes frequently eat sugar before engaging in contests, and soldiers are given sweets as part of their regular food allowance on long hard marches. Starches and sugars are changed to glucose in the processes of digestion. If more sugar is eaten than is necessary for the fuel needs of the body, the extra sugar is stored as glycogen in the liver and the muscles. This glycogen serves as a reserve store of energy. Additional extra stores of carbohydrates are changed to fats and are stored among the various body tissues.

If too great a proportion of carbohydrates is included in the diet, a person is liable to become too fat or to develop diabetes. The daily diet, however, should include one or more vegetables rich in carbohydrates.

**Fats.* The daily diet to be properly balanced should contain some fat, such as butter, oleomargarine, or animal fat. Fats (Fig. 177) are not quickly digested — in fact, the more fat that is eaten with a meal, the more slowly the meal digests. There are great differences also in the relative digestibility of various fats. Olive oil and pork fat, for example, are more quickly digested than mutton fat. These statements do not mean, however, that foods

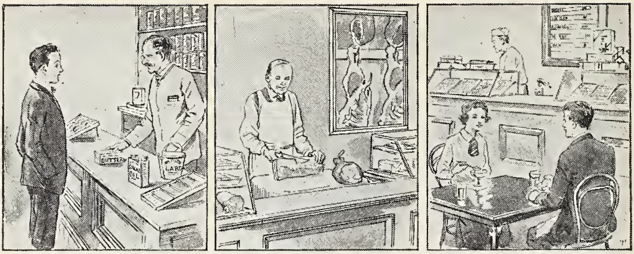


Fig. 177. What foods containing fats are shown in these pictures? What evidence can you state to prove that fats give more Calories per gram than either carbohydrates or proteins?

which digest quickly are necessarily more valuable than those which require a longer time to digest. The contrary is often true. Fats cannot be absorbed directly into the body as can sugars. They must first undergo certain chemical changes in the process of digestion.

Although most of the fatty tissue in the body is deposited as a result of eating more than enough carbohydrates, nevertheless extra fat in the diet is also stored. An adult should be watchful lest he become too fat; yet some fatty tissue in the body has value. Aside from its use as a future store of fuel, fat in the body is a good insulator[1] of heat and also serves as a cushion to protect delicate organs from shock.

The high Calorie content of fats makes them valuable in cold countries and in cold weather. Fruits and vegetables, which contain smaller percentages of energy foods than meats, should make up the larger portion of the diet in warm countries or in hot weather.

**Proteins.* Unlike carbohydrates and fats, proteins serve not only as fuel but also as material for building and replacing protoplasm. Protoplasm is composed largely of proteins, which in turn are composed of certain compounds (amino acids). Nineteen different amino acids are known.

[1] *Insulator* (in'su la ter): a substance which prevents heat or electricity from being conducted to or away from a body.

FIG. 178. How many protein foods can you name in three minutes?

All carbohydrates and fats are composed only of carbon, hydrogen, and oxygen in varying proportions, depending upon the nature of the sugar, starch, and fat. Proteins are likewise made up of carbon, hydrogen, and oxygen, but in addition all contain nitrogen; some contain also sulfur, phosphorus, and other elements. The diet each day should therefore include some protein in the form of meat or some meat substitute, such as eggs or cheese.

Proteins are found in beans, peas, nuts, and many other vegetable foods, as well as in meats and animal products, such as milk and cheese (Fig. 178). Certain excellent sources of proteins would not serve at all if they were the only food eaten. Gelatin, for example, which is made from bone and connective tissue, lacks three of the amino acids which are necessary to protoplasm. Hence if gelatin were the only protein source eaten, the body would waste away. Therefore, although the total amounts of protein needed by the body are far less than the amounts of carbohydrates and fats, nevertheless our diet should include a wide variety of proteins in order to provide all the amino acids of which our protoplasm is composed. The proteins of meat are, moreover, somewhat better builders of human protoplasm than are vegetable proteins.

When too much protein food is eaten, the extra amount cannot be stored but is burned as fuel. Since, however, the nitrogen in the protein will not burn, chemical changes take place first, separating the nitrogen compounds. These are eliminated at once from the body.

Food Value of an Average Serving of Certain Food Materials[1]

Food	Measure	Calories			Total Calories
		Protein	Fat	Carbohydrate	
Apple	$\frac{1}{2}$ large	2	3	45	50
Asparagus	4 stalks, 4 in. long	3	1	6	10
Bacon	4–5 small slices	13	87	...	100
Banana	1 medium	4	4	67	75
Beans, dried	$\frac{1}{4}$ cup	45	8	118	171
Beans, lima, dried	$\frac{1}{4}$ cup	42	8	150	200
Beans, lima, fresh	$\frac{1}{2}$ cup	23	5	72	100
Beans, string, fresh	$\frac{1}{3}$ cup	3	1	11	15
Beef, lean, round	2 slices, 4 × 3 × $1\frac{1}{8}$ in.	96	104	...	200
Beets	$\frac{1}{3}$ cup, cubes	3	1	21	25
Blackberries	$\frac{1}{2}$ cup	9	16	75	100
Boston brown bread	$\frac{1}{2}$ in. slice, 3 in. diam.	7	6	54	67
Bran, wheat	$\frac{1}{4}$ cup	8	3	43	54
Bread, graham	1 slice, $3\frac{1}{4}$ × 2 × $\frac{3}{8}$ in.	5	2	26	33
Bread, white	1 slice, 3 × $3\frac{1}{2}$ × $\frac{1}{2}$ in.	7	3	40	50
Butter	pat, 1 T.[2]	1	99	...	100
Buttermilk	$\frac{1}{2}$ pt.	29	12	48	89
Cabbage, chopped	$\frac{1}{2}$ cup	2	1	7	10
Cake, sponge, 2 eggs, hot water	1 piece, 3 × $2\frac{3}{4}$ × $\frac{7}{8}$ in.	11	10	129	150
Cantaloupe	$\frac{1}{4}$ melon	3	...	47	50
Carrots, cooked	2 medium	4	2	34	40
Cauliflower	$\frac{1}{5}$ small head	5	3	12	20
Celery	$\frac{1}{4}$ cup	2	...	4	6
Cheese, American	cube, 1 in.	23	63	3	89
Cheese, cottage	$3\frac{2}{3}$ T.	49	2	11	62
Cherries, stoned	$\frac{1}{4}$ cup	1	2	22	25
Chicken, roast	1 slice, 4 × $2\frac{1}{2}$ × $\frac{1}{4}$ in.	51	49	...	100
Corn, canned	$\frac{1}{3}$ cup	11	11	78	100
Corn, fresh	1 ear, 6 in.	6	4	40	50
Corn meal, cooked	$\frac{2}{3}$ cup	10	5	85	100
Cream, thin	2 T.	2	43	5	50
Dandelion greens	$\frac{1}{2}$ cup	12	11	52	75
Dates, unstoned	3–4	2	7	91	100
Egg white	1	13	1	...	14
Egg, whole	1 egg	25	45	...	70
Egg yolk	1	11	45	...	56
Figs	3 large	10	2	188	200
Fish, lean, broiled	1 slice, 4 × $2\frac{1}{4}$ × 1 in.	81	52	...	133
Gingerbread, plain	1 piece, 2 × $1\frac{2}{3}$ × 2 in.	14	42	144	200
Grapefruit	$\frac{1}{2}$ large	7	4	89	100
Grapes, white	22	5	15	80	100
Ham, boiled	1 slice, $4\frac{3}{4}$ × 6 × $\frac{1}{8}$ in.	44	106	...	150
Honey	1 T.[2]	1	...	99	100

[1] Compiled from various sources: M. S. Rose, *Laboratory Handbook for Dietetics*; M. S. Rose, *Feeding the Family*; H. C. Sherman, *Food Products*; and others.
[2] T. = Tablespoonful.

Food Value of an Average Serving of Certain Food Materials

Ice cream	2/3 cup	13	202	105	320
Lamb chop, broiled . .	1 chop	40	60	...	100
Lamb, roast	1 slice, 3 1/2 × 4 1/2 × 1/8 in.	41	59	...	100
Lettuce	1/4 head	3	2	7	12
Liver, calf's, broiled . .	medium-sized serving	62	38	...	100
Macaroni, cooked . . .	1/2 cup	7	1	42	50
Maple sirup	2 T.	...	...	133	133
Milk, whole	1/2 pt.	34	88	48	170
Molasses	2 T.	4	...	129	133
Mutton, roast	1 slice, 3 × 3 3/4 × 1/8 in.	33	67	...	100
Oatmeal, cooked	2/3 cup	11	11	45	67
Olive oil	1 T.	...	100	...	100
Olives, green	4 medium	1	41	8	50
Onions	3 to 4 medium	13	6	81	100
Orange	1 medium	5	2	68	75
Orange juice	1/2 cup	...	...	50	50
Oysters, raw	1/2 cup	37	18	20	75
Peaches	3 medium	6	3	91	100
Peanuts	20–24 single nuts	19	63	18	100
Peas	3/8 cup	14	2	34	50
Peas, dried	3/8 cup	70	6	177	253
Pecans	12 meats	5	87	8	100
Pineapple	2 slices, 1 in. thick	4	6	90	100
Pork chop, lean	1 chop	64	136	...	200
Potato, sweet	1 medium	12	10	178	200
Potato, white	1 medium	11	1	88	100
Prunes	4 medium	3	...	97	100
Raisins	1/4 cup	3	9	88	100
Rhubarb	1 cup	2	7	16	25
Rice, white, steamed . .	3/4 cup	9	1	90	100
Sirup, corn	1 3/4 T.	...	...	100	100
Spinach, cooked	5/8 cup	3	2	20	25
Squash, cooked	1/2 cup	4	5	46	55
Strawberries	2/3 cup	5	7	38	50
Sugar	1 T.	...	...	50	50
Tomato, fresh	1 small	4	4	17	25
Turnip, cubes, raw . . .	1/2 cup	3	1	21	25
Veal leg, lean, broiled. .	1 serving	105	45	...	150
Walnuts, English . .	8–16 meats	11	82	7	100

The number of Calories one needs varies not only with one's work (as was explained on page 263) but also with age and sex. Thus a child two years of age needs about 900 Calories per day, and this number increases at about the rate of 100 Calories for each year until the child is twelve. Between twelve and fourteen years a girl needs about 2100 Calories per day. A girl of fifteen or sixteen and a boy of thirteen or fourteen need about 2400 Calories. A boy of fifteen or sixteen needs about 2700 Calories. One author states that about one sixth of the Calories should be supplied by proteins, about one fifth by fats, and the rest by carbohydrates. From these facts and those in the table above prepare some daily diets which would serve for boys and girls of various ages, and which would serve for men requiring the number of Calories indicated on page 263.

Fig. 179. A mother zebra and her colt at the Detroit zoo. What advantages do wild zebras probably derive from having striped bodies?

Milk the one best food. The young of all the higher animals eat only milk as food during the earliest parts of their lives (Fig. 179). Human babies are often fed from birth upon cow's milk to which has probably been added some sugar, water, and perhaps other substances. Cow's milk, however, is usually not so good for them as their own mother's milk.

*Although milk is nearly 90 per cent water, it also contains fats, proteins, and carbohydrates. Moreover, it contains salts of calcium and phosphorus, which are necessary for bone-building. It also contains important vitamins. Authorities differ with respect to the amount of milk which children and older people should consume, but they are agreed that milk has an important place in the diet of practically everybody. Growing children should drink about a quart of milk every day, in order to be sure of securing enough calcium for the proper growth of bones. In rare cases in which the milk is found to cause digestive disturbances, the necessary quantities should be taken in soups, creamed vegetables, meat dishes, and desserts. The fact that milk is deficient in some necessary substances, especially iron, makes necessary the addition of other foods to the diet of all but very young children.

Self-test on Problem XIII–D. 1. Fats furnish (1) half; (2) nearly twice; (3) three times; (4) more than twice; (5) just as many Calories of energy per gram as do carbohydrates or proteins.

2. Which of the following terms does not belong with the rest: (1) grape sugar; (2) proteins; (3) glucose; (4) cornstarch; (5) honey; (6) glycogen; (7) energy; (8) food?

3. If more carbohydrate food is eaten than is needed by the body, the excess is stored in the body as *protein.*

4. Which of the following terms does not belong with the rest: (1) olive oil; (2) cornstarch; (3) lard; (4) butter; (5) tallow; (6) corn oil?

5. In general *less* fat is deposited in the body from eating an excess of fats than from eating an excess of carbohydrates.

6. Of the foods, only *fats* serve to build and to replace protoplasm.

7. Which of the following terms does not belong with the rest: (1) olive oil; (2) honey; (3) very lean meat; (4) cheese; (5) peanuts; (6) eggs?

8. The best all-round food is *beefsteak.*

Problem XIII–E · What are Some Important Facts which one should Know about the Non-energy Foods and the Substances they Contain?

***Vitamins.** It has long been known that people who were forced to live for long periods under conditions which were not normal were liable to contract a variety of serious diseases. Soldiers in time of war, people in besieged castles and cities, people in famine countries, sailors on long voyages — all came to suffer from diseases which rarely affected people living under ordinary conditions. It was not known until fairly recently, however, that such diseases were "food-deficiency diseases," — that is, diseases caused by the lack of certain necessary substances, called vitamins, in the diet (Fig. 180), mostly contained in fresh fruits, whole cereals, and vegetables. When these foods were restored to the diet, the sufferers usually recovered.

The importance of vitamins and the consequent interest in them have caused a number of fads. Moreover, a number of commercial products have been widely advertised and sold at high prices because they were represented to contain certain necessary vitamins. It is true that some foods contain more of certain vitamins than do others. Yet the vitamins are found so widely distributed and are needed in such small quantities that the

ordinary well-rounded diet is likely to furnish all that are needed. A daily diet which includes both fruit and green vegetables of which one at least is raw will go far toward supplying the needed vitamins.

FIG. 180. Special Report: What are the effects of lack of other vitamins? (Consult a textbook of physiology or an encylopedia)

The chemical composition of none of the vitamins has yet been determined. Hence they cannot be given chemical symbols, as can fats, carbohydrates, and proteins. They are therefore known by letters. At least six vitamins are now known (Fig. 181). It is interesting to note that one of the sources of vitamin D is the action of the ultraviolet rays of sunshine on the skin. Ultraviolet rays are light waves which are too short to be seen as colors. In great cities the sunshine sometimes fails to produce such desired action, because the great amounts of smoke and dust in the air absorb the ultraviolet rays before they can reach the ground. City dwellers, especially children, do well therefore to add to the daily diet cod-liver oil, halibut-liver oil, salmon-liver oil, or viosterol.

Vitamins, with possibly the exception of D, are of vegetable origin. Yet when eaten by animals they are not destroyed but may be stored for a considerable time in various organs and are passed into milk or eggs. Peoples like the Eskimos, who live for long periods wholly upon meat, secure their vitamins by eating the vital organs, especially the livers, of animals.

Mineral salts. About 4.4 per cent of the weight of the body is due to the inorganic salts which it contains. Most of these salts

FIG. 181. This drawing was made by a high-school student of biology. Can you name other sources of each vitamin than those she has represented?

are in the bones. These salts are chiefly compounds of sodium, potassium, calcium, magnesium, iron, chlorine, phosphorus, sulfur, carbon, fluorine, and iodine. Small quantities of minerals are therefore an essential part of the diet. Of these minerals, sodium chloride, or common table salt, is the one with which you are probably most familiar.

Animals which eat only flesh usually do not crave salt. Eskimos, who live chiefly on flesh, do not desire it and will, in fact, reject salty food. But animals and people living on a wholly or partly vegetable diet find it necessary to eat salt. Animals will travel long distances to secure salt. Recognizing this need, the directors of our national parks place blocks of salt here and there in the woods for the deer to lick. If one ate only meat, it would contain sufficient salt to furnish all that the body needs. But when one eats vegetables, chemical changes are induced which cause the body to eliminate salt. This must, of course, be replaced.

Salt has an added value as a condiment, since it gives a pleasant flavor to foods and therefore stimulates[1] the flow of digestive

[1] *Stimulate* (stim'u late): to cause something to act.

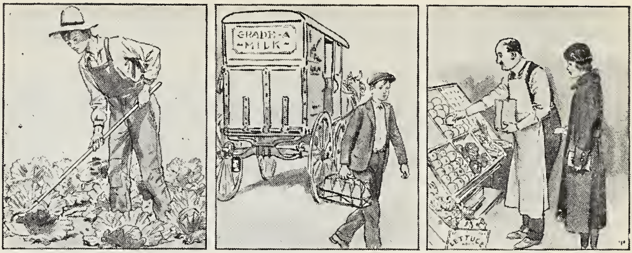


Fig. 182. What other foods containing mineral salts can you name?

juices. Most people, however, use considerably more salt than is needed. There is a possibility of harm from using too much salt.

The body needs and uses inorganic salts other than table salt in considerable variety, but ordinary foods contain a sufficient supply of these salts (Fig. 182). Drinking water also is a source of some needed minerals. The lack of sufficient quantities of calcium salts, used in bone-making, is accompanied by serious consequences. These salts also have an important function in connection with the irritability of muscles and nerves. Bread and milk are rich in calcium salts.

Laboratory of Animal Nutrition, Cornell Univ.

Fig. 183. A dog with goiter. The thyroid gland became so large that it finally choked the dog to death. What substance did the diet of this dog probably lack?

Anemia is due to lack of iron salts in the body. Mild cases can often be cured by changing the diet to include foods rich in iron salts, such as liver, spinach, yolk of egg, asparagus, prunes, beef, cabbage (the green leaves), and apples. Goiter, a serious and sometimes fatal disease which is accompanied by an enlargement of a certain gland (thyroid) in the neck, is often caused by lack of iodine salts in the diet (Fig. 183).

***Water.** Since protoplasm consists largely of water, no organism can exist long without new supplies. Water is necessary to

the body in several ways: (1) to supply and renew the amounts needed in the tissues; (2) to dissolve various food substances, waste substances, and other chemical compounds in the body; (3) to transport substances within the body, for example, foods and waste materials through the digestive system, and digested foods, oxygen, carbon dioxide, and other substances through the blood stream.

The body gets rid of water through the action of the kidneys, of the sweat glands, and of the lungs. The losses of water in the body must be made up. Part of this necessary water is replaced by the food we eat, since no food is entirely lacking in water and since the green-vegetable foods are mostly water. Part is replaced by the water which results from the burning of the fuel in the body and to a smaller extent from other chemical processes concerned with digestion. If the water secured to the body from these sources is not sufficient, additional water must be drunk (Fig. 184).

It is not unusual to find among rules of health a statement to the effect that everybody should drink at least six glasses of water every day. This statement may possibly be true of people on the average, but is not necessarily true for every person. One's needs for water vary from day to day, depending upon the food one eats, the amount of exercise one takes, and upon weather conditions — temperature, humidity, and the like. Whenever our bodies need additional water, we become thirsty and remain thirsty until we have drunk the amount needed by the body. Our thirst, then, and not fixed rules will be our best guide as to how much water we should drink. Some water with our meals is probably of benefit. But too much water is likely to dilute the digestive fluids too much. Our food should be sufficiently chewed so that it can be easily swallowed without the need of washing it down with water.

Food flavors and condiments. Much of the value of our food is derived from its odor, flavor, and appearance. The sight of attractive food causes the mouth to water; that is, it starts a flow of saliva. Moreover, the tempting odors and flavors of foods during eating stimulate the flow of digestive juices in the stomach. Condiments, such as mustard, horse-radish, pepper,

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Fig. 184. Sheep on a Wyoming ranch. Sheep and goats can get along without drinking, and many desert animals never drink at all. From which of the sources of water mentioned in the text must these animals receive the water they need?

and other spices, are used in wide variety in civilized countries for the sake of improving the flavor of foods.

Stimulants. Coffee, tea, and cocoa or chocolate contain substances (respectively caffeine, theine, and theobromine) which are nerve stimulants.[1] When taken moderately they reduce both mental and physical fatigue. Thus they make it possible for one to continue mental work for longer periods than without them. Moreover, if used moderately, neither coffee nor tea is likely to be harmful to adults, though people who are nervous or whose digestion is not normal should avoid their use. When coffee or tea is boiled with the grounds, another substance (tannin) is dissolved. This substance is distinctly harmful to the digestive system. Young people should not drink either tea or coffee. Neither tea nor coffee, however, is dangerous in the sense that alcohol is dangerous. The stimulant in cocoa or chocolate is much milder in its action than the stimulant in tea and especially in coffee. Cocoa and chocolate, moreover, unlike coffee and tea, are sources of some energy since they contain some fats, carbo-

[1] *Stimulant* (stim'u lant): that which excites or makes more than normally active.

hydrates, and proteins. The fact that these drinks are usually made with milk adds greatly to their food value. Cocoa and chocolate are not likely to harm anybody unless taken to excess.[1]

Economy in foods. Most people eat far more food than they need. The people of certain Oriental countries thrive on a quantity of food so small per person as compared with what the average citizen of the United States eats that their food allowance would seem almost like starvation. Overeating is liable to bring on diseases, as well as other serious consequences.

Most people are likely, moreover, to pay more for foods than is necessary. It is a fortunate fact that many of the cheapest foods are among the most nourishing. The cheaper cuts of meats, for example, are as nourishing as more expensive ones, and if properly cooked are highly palatable. Cheese and eggs will often supply needed proteins at a cost below that of meat. Furthermore, these substitutes contain valuable vitamins which most cuts of meat lack. In foods, however, the cost per pound does not always indicate the true relative cost. Certain cuts of meat, for example, which may cost little per pound may be relatively expensive because they contain so much waste in gristle and bone. Other foods may be expensive, though low in price, because they contain such large proportions of water.

Self-test on Problem XIII–E. **1.** Five different classes of nonenergy foods are --(?)--, --(?)--, --(?)--, --(?)--, and --(?)--.

2. Fresh fruits are valuable in the diet as a source of *proteins.*

3. Milk and eggs are a valuable source not only of energy but also of *Calories.*

4. Two cheap and common sources of bone-building minerals are --(?)-- and --(?)--.

5. A disease which can sometimes be cured by eating foods rich in iron salts is *hydrophobia.*

6. Name three purposes served by water in the body.

7. In general tea and coffee are not harmful to *children.*

8. A food which is both a stimulant and an energy food is *tea.*

[1] To the Teacher. If it seems desirable at this point to consider additional relations of food to health, material will be found in Chapter XXIV.

Self-test on Organization of Facts. Make a complete outline listing the classes of foods, somewhat in this manner:

FOODS

I. Essential foods
  A.
    1.
    2.
    Etc.
  B.
    1.
    Etc.
II.
  A.
    Etc.

Self-test on Biological Principles. 1. How do the food-getting habits of the sponge illustrate the beginnings of division of labor?

2. What facts can you state from this chapter which seem to prove this principle: "In general the more complex an animal is, the more complex are its food-getting structures."

Self-test on Making Comparisons. 1. The starfish feeds mostly on such animals as the clam and the oyster. It crawls about until it finds a victim. Then bending its arms down around the shell, it fastens its tube feet to the two halves of the shell (Fig. 185). The starfish, by straightening out its arms, slowly begins to pull the two halves of the shell apart. Since the starfish can depend on water pressure to hold its tube feet against the shell, it never seems to get tired. But the oyster does. In twenty or thirty minutes the oyster becomes too tired to continue the unequal struggle longer. Its shell is slowly pulled open, and the helpless oyster is now ready to be eaten. But the mouth of the starfish is small. The oyster is too large to go into it. How will the starfish manage to get the oyster into its mouth? The answer is, it does not. Since food cannot be taken into the stomach, as in most animals, the stomach goes out to the food. The starfish forces its stomach

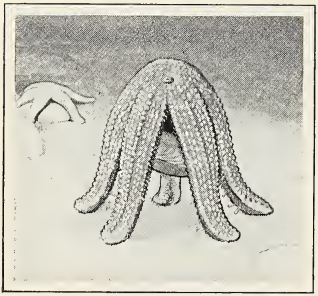


FIG. 185. Starfish opening an oyster. To which of the types of enemies listed on page 24 does the starfish belong?

out through its mouth and wraps it around the oyster. Digestive juices are poured out which reduce the food to a liquid, so that it can be absorbed by the stomach. When the oyster has all been digested and absorbed, the stomach is drawn back by the muscles which fasten it into each arm, and the starfish goes on its way again. Compare the means by which starfish secure food with those of the other animals discussed in this chapter.

2. Recall what materials the roots of green plants absorb from the soil, and how they absorb these materials. How are the materials and the processes like and how are they different from those of the dependent plants?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Honey is an organic product used as food by certain animals. Can you name other organic products which serve as food?

2. Can you explain how the water pressure helps to hold the tube feet of the starfish against the oyster shell?

3. List the common snakes you know which you have observed to eat insects; to eat birds; to eat other snakes; to eat amphibians, such as frogs, toads, or salamanders; to eat small rodents, such as field mice, rats, and gophers.

4. What other types of bird beaks (than those mentioned in the text) do you know? How do they especially fit each bird for the sort of food it eats?

5. List the common birds you know which you have observed to eat insects; to eat carrion, or decaying flesh; to eat seeds; to eat fruit; to eat other birds; to eat small mammals.

6. Can you give one or more examples of each of the parts of plants which were named as being used as food?

7. How many carbohydrate foods can you list in five minutes?

8. Why is a diet exclusively of milk not a good one to follow?

9. How many fatty foods can you name in five minutes? Why do people living in cold climates eat more fat than those living in the tropics? What advantages do animals such as seals, walruses, and whales derive from having thick layers of fat under their skins?

10. How many of the animals discussed in this chapter move about seeking or hunting for food? How many remain in one spot merely absorbing or capturing what comes near? How many other animals can you name which belong in the two classes indicated in these questions?

11. In which of the three ways enumerated on page 277 is water used by plants?

Exercise on Scientific Attitudes. The history of the use of gelatin as a food illustrates well how scientific knowledge grows. Because gelatin was found to be both rich in nitrogen and easily soluble, scientists thought that it would prove to be an unusually nourishing food. During the French Revolution (1789–1795) a committee investigated the nourishing qualities of gelatin. Its report was favorable, as was also that of a later commission from the French Academy in 1814. On the basis of this latter report gelatin came to be largely used as nourishing food in hospitals. It proved so unsatisfactory, however, that doubts arose concerning its value as a nutrient. Accordingly a second gelatin commission was appointed by the French Academy (1841), another by the Netherlands' Institute (1844), and still another by the Academy of Medicine in Paris (1850). These three commissions reversed the opinions announced by the earlier scientific commissions. All three independently reported that gelatin has no value as nourishment, and that it is harmful rather than beneficial as a food. Later experiments, however, determined the fact that while gelatin lacks certain amino acids, without which the body cannot repair tissue, nevertheless it possesses certain food values. Which of the scientific attitudes (pp. 12–13) are illustrated by this story?

Exercise on Scientific Method. 1. Constructing a Hypothesis. A hypothesis is an attempt to make a reasonable explanation of facts or to make a prediction of how or why something happens or is done. Can you make a hypothesis which may explain how an earthworm can get food into its mouth? Here are some necessary facts upon which to base your hypothesis: The earthworm has a mouth with no teeth. It is able to expand and contract the walls of the cavity behind its mouth (Fig. 112, p. 177). The earthworm pushes its mouth against the soil so tightly that no air can enter its mouth. It then increases the size of the cavity behind its mouth. Soil enters its mouth. Why?

2. Making Inferences. What sort of food does a caterpillar eat? What does a butterfly eat? What change, then, must occur in the type of mouth during the pupa stage?

Special Reports. 1. How is milk pasteurized in a modern dairy? What are the conditions which a dairy must meet in order that its product may be marketed as "Certified Milk"? as "Grade A Milk"? What is meant by "tuberculin-tested cows"?

2. What are the characteristics of scurvy, beriberi, pellagra, rickets? In what parts of the world are they most common?

Chapter XIV · Preparing Food Energy for Use by Protoplasm (Digestion)

Questions this Chapter Answers

Why is digestion of food necessary?
What is digestion?
What is the function of enzymes?
How is digestion carried on in plants?
How is digestion carried on in typical animals?
How are teeth related to digestion?
What digestive functions are performed by the mouth?
What digestive functions are performed by the stomach? by the small intestine? by the large intestine?

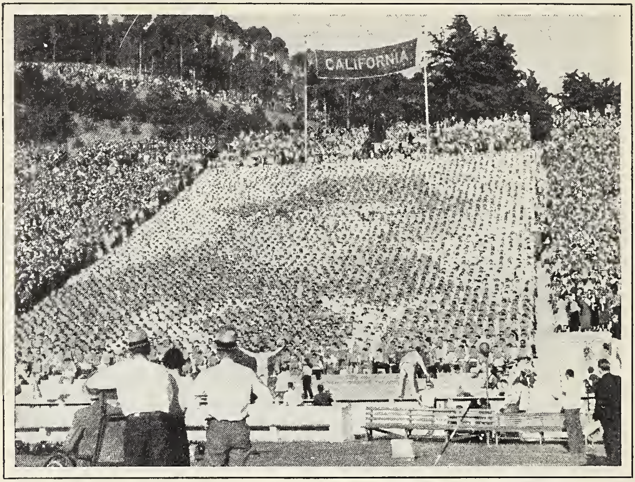
Problem XIV-A · What is the Nature of Digestion?

Why food must be digested. The nutrient foods are seldom of any use to the organism in the form in which they are procured. A fish would serve no purpose to a larger fish, to a sea gull, to a cat, or to a man just as it is captured. A loaf of bread just as it is baked would be of no more use than a rock of the same size and shape unless it could somehow be changed so that the body could use it. The substances which serve as nutrient foods, therefore, must all be substances which can be so changed within the organism that they can be both absorbed and later used by the various cells and tissues.

***What is digestion?** The term *digestion* is used to include all the processes by which any food substance is changed so that it can be used by the organism for energy and growth and for replacement[1] of cells. The processes of digestion include both physical and chemical changes. Only the nutrient foods — carbohydrates, proteins, and fats — need to be digested. The other food substances which the body uses are absorbed in the form in which they are eaten.

A thorough understanding of digestion in man is made easier by a brief study, first, of digestion in plants and in some of the lower animals. And since digestion in every organism is brought about

[1] *Replacement* (re place′ment): process or result of restoring or replacing.



Associated Students News Bureau, University of California

Fig. 186. Stimulating the team. Can you think of ways in which the cheering section, with their school colors and school yells, have a somewhat similar function with respect to the team's action to that of an enzyme with respect to digestion?

by substances called enzymes, it is necessary to know something about the nature and various important functions of enzymes.

Enzymes. There are many substances found in the study of chemistry which affect the speed of a chemical reaction without themselves taking part in it. Manganese dioxide, used in preparing oxygen from potassium chlorate, is an example of such a substance. In the study of plant and animal digestion we find a great number of such substances, called enzymes. These are largely effective in bringing to completion the various processes of digestion by causing the food substances to undergo chemical changes by reacting[1] with water. The enzymes themselves do not combine with the food or undergo changes of any sort (Fig. 186). A small amount of an enzyme, therefore, can bring about the digestion of a great amount of food. Moreover, the enzyme can continue to act for an indefinite time.

[1] *React* (re akt′): to enter into chemical combination.

Nobody yet knows just what the chemical nature of any one of these enzymes is. It is believed, however, that all are organic in nature. Each, moreover, is effective in hastening a certain part of the digestive process, and is effective in no other. Enzymes are most effective at about 40° C. to 50° C. They have no effect at the freezing temperature of water or at its boiling point; at the latter temperature they are totally destroyed — in fact, most of them are destroyed at 60° C.

Self-test on Problem XIV–A. **1.** Only the *energy* foods require to be digested.

2. A substance which causes the digestion of foods without itself being changed is called a *vitamin*.

3. Before the body can use food, the food must undergo physical and chemical changes which together make up the process of __(?)__.

4. Anything like ice water is likely to *increase* the speed of digestion. Explain this statement as you think it should be made.

Problem XIV–B · How do the Digestive Systems of the Lower Organisms Differ from those of the Higher Organisms?

Digestion in plants. In the simplest plants, such as the bacteria, there is no digestion within the cell. The cell secretes enzymes which pass out through the cell wall, digesting the food material outside. The digested food is then absorbed into the cell by the process of osmosis.

Experiment 63. Does digestion take place — that is, is starch changed to sugar — in germinating seeds? Germinate some bean seeds or corn seeds in sphagnum moss or in moist sawdust. Grind some of the germinated seeds and also some dry seeds of the same kind for a control. Test a sample of each both for starch and for sugar (see Experiments 12 and 78, pp. 58 and 265). Answer with a complete statement the question asked at the beginning of this experiment.

Experiment 64. Does diastase digest starch, that is, change it to sugar? Into a test tube put a little starch. Add warm water and a little diastase. Into a second test tube put an equal quantity of starch and warm water. Keep the test tubes side by side in a warm place for an hour. Test the contents of each for both starch and sugar. State your conclusions in a complete sentence or two.

Exercise on scientific method (using controls). What was the control in this experiment? Why was it used?

Fig. 187. Gathering sap from sugar-maple trees in New England. Self-test on Mastery of Facts: Explain the processes which take place in the tree as a result of which man is able to secure the sap from which maple sugar is made. You may wish to review Unit II

*In green plants starch is manufactured by photosynthesis in every cell containing chlorophyll. The starch, however, is solid and insoluble. Hence it cannot be used directly as food by the plant. The starch molecules must therefore be changed into other molecules which will go into solution. Through the action of an enzyme (diastase) the molecules of starch are changed to molecules of sugar. These dissolve in water and pass readily through the cell walls of the plant. The sugar finds its way from the cells into the sap and is circulated throughout the plant, passing into every part and serving to nourish each cell.

When the plant needs to draw upon its reserve food supplies, this stored food must be digested a second time in order that it may again be soluble in the sap and may be carried to the parts where it is needed (Fig. 187). The starches, proteins, and fats, therefore, are changed by enzymes (respectively diastase, protease, and lipase). Probably every active plant cell secretes enzymes of one sort or another.

Digestion in animals. In the lowest forms of animal life, as in the lowest plants, the process of digestion is very simple. With the one-celled animals, for example, the food is attacked by enzymes and digestion takes place within the cell. In many of the

simpler Metazoa which have no special organs of digestion, digestion is accomplished by certain cells. In the sponge, for example, the food is captured and digested mostly by the cells around the openings of the many pores. Each of these food-getting cells acts as if it were a separate organism in so far as securing and digesting food is concerned (Fig. 188). The cells which are able to capture and digest food furnish digested food to all those which cannot.

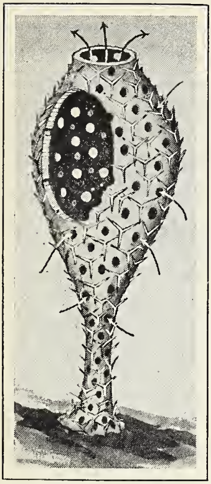


Fig. 188. Diagram of a simple sponge. In this figure a portion of the wall is cut away to show the structure. To what extent is digestion of food in the sponge like that in *Amœba*?

Hydra has no digestive organs such as the higher animals have. It has a mouth and a crude stomach represented by the irregular interior cavity of the body (Fig. 189). Most of the food is digested in this cavity (the gastrovascular cavity) by enzymes secreted by the cells of the inside layer (the endoderm layer). Food particles which are not thus digested are captured by the separate cells of the inside layer in much the same way that an amœba captures its food, and are digested within these cells by their enzymes.

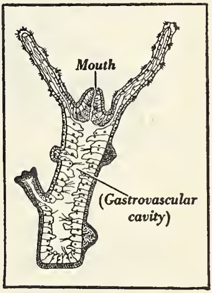


Fig. 189. Diagram of a hydra. In what two regions does *Hydra* digest food?

Animals higher in the scale of life than *Hydra* have special organs of digestion. In certain of the flatworms which are not parasites, there is a mouth and a fairly simple intestine (Fig. 190). Part of the food is digested in the branches of the intestine. The rest is engulfed and digested by the living cells, as in simpler animals. In both *Hydra* and the flatworm, however, the food cavity has only one opening. The undigested food and the body wastes are discharged through the mouth.

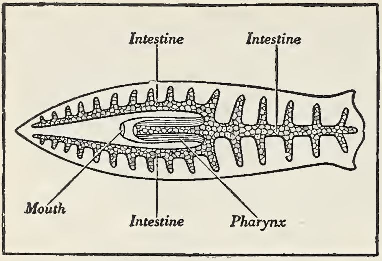


FIG. 190. The flatworm has primitive digestive organs. Can you recall other flatworms which can use only food that is already digested?

A study of a more complex animal, such as the earthworm (Fig. 191), reveals a still more complex digestive system. It includes an esophagus,[1] leading from the mouth, a crop for food storage, a gizzard for grinding the food, and a straight intestine. This intestine extends through the remaining length of the body to a second opening (anus), through which the waste materials are discharged. Most of the digestion takes place in this intestine.

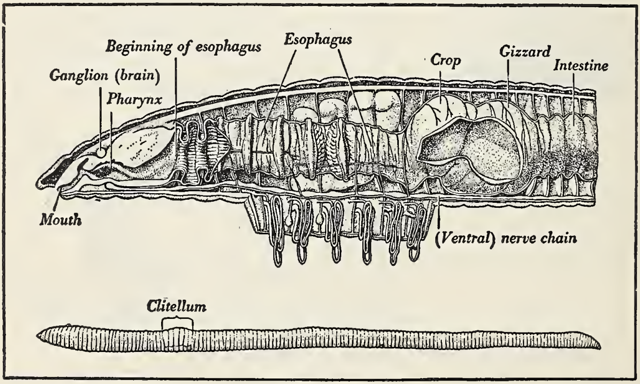


FIG. 191. In what respects is the digestive system of the earthworm more complex than the digestive system of the flatworm (Fig. 190)?

The processes of digestion in the earthworm are much like those in the higher animals, including man. Glands in the linings of the pharynx and the esophagus mix necessary fluids with the

[1] *Esophagus* (e sof′a gus): the tube through which food and drink pass from the mouth to the stomach; the gullet.

food to make its digestion possible. It is believed that the enzymes which accomplish digestion in the earthworm and the final

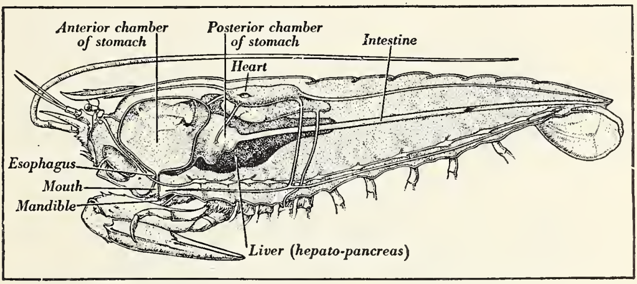


FIG. 192. In what respects is the digestive system of the crayfish more complex than that of the earthworm (Fig. 191)?

substances into which the food is changed by the processes of digestion are the same as those in the digestive system of man.

In animals higher in the scale of life, the arthropods (Fig. 192), are found jaws and teeth for biting, holding, and crushing food.

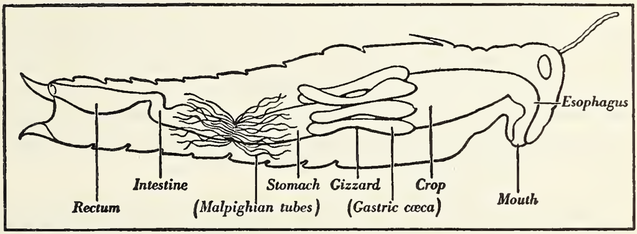


FIG. 193. What organs of digestion do both the grasshopper and the earthworm have? Has either any digestive organs which the other has not?

In insects, such as the grasshopper, the intestine is slightly coiled (Fig. 193). In this most of the digestion is accomplished by enzymes. There is also a large intestine, where wastes are stored before elimination, as in the higher animals. In the chordates the digestive systems are almost like that of man.

***Summary.** From the preceding paragraphs it will be seen that the simpler plants and animals have each a very simple

apparatus which serves its needs for digesting foods. A more complex organism, however, must have a digestive apparatus

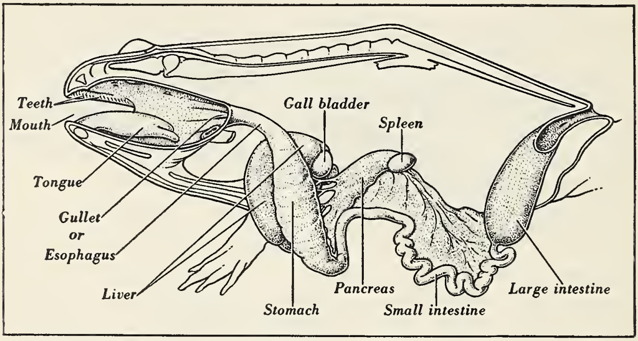


FIG. 194. Compare the digestive system of the frog with that of man (Fig. 197, p. 294). Why would one expect the digestive system of man to be more like that of a frog than that of a grasshopper?

which is more complex. There is a greater division of labor in the digestive system, the more complex the organism is. The organism can survive only if its digestive system, like all its other parts and systems, is adapted to its general structure, its food, and other factors. The higher in the scale of life an organism is, the more nearly its digestive system resembles that of the higher animals (Fig. 194), and the less nearly its digestive system resembles that of the simplest animals.

Self-test on Organization of Facts. Various animals were used in this problem to illustrate the various stages in the development of the digestive systems from the lowest to the highest animals. Can you name the animal used to illustrate each stage listed below, and can you name also the phylum to which each belongs (you may need to review briefly Unit III)?

1. No special structure; no division of labor.

2. The beginnings of division of labor; some cells digesting food for others.

3. A mouth and a very primitive digestive cavity.

4. A simple intestine, having only one opening but digesting part of the food of the animal.

5. A fairly complex food tube, having two openings, having various parts and compartments for different purposes, and having also glands making digestive juices.

Self-test on Problem XIV–B. 1. In the bacteria *all* digestion takes place *inside* the cell.

2. Before plants can use starch as food, it must be changed by *vitamins* into *protein.*

3. Sugar in plants is changed by *protoplasm* before it can be stored as fats, proteins, and __(?)__.

Problem XIV–C · What are Some Important Factors in Relation to Digestion in the Human Mouth?

Relation of teeth to digestion. With man digestion begins in the mouth. With other animals, whether digestion begins in the mouth or not depends on the nature of the nutrient foods eaten by the animal. With every animal that has teeth, the teeth bear a close relation to the food habits of the animal, to the type of jaw, and to the way in which the jaw functions.

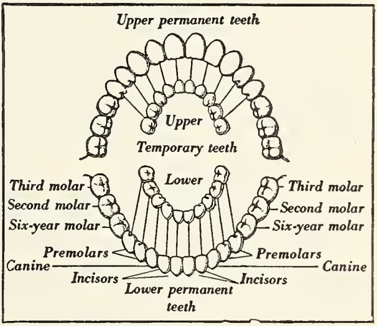


FIG. 195. Temporary and permanent teeth. The twenty "baby" teeth are called deciduous because they are later shed, or lost. In what respects are deciduous teeth like the leaves of deciduous plants?

If, therefore, one were to compare the teeth of a dog with those of a man, one would find several respects in which they were much alike and important respects in which they were different. One would find the dog's incisors similar to the man's (Fig. 195). The canine teeth would be somewhat similar, though much longer, because the dog's ancestors needed long canine teeth for seizing and holding their prey. But one would find that the dog, unlike

man, uses his premolars[1] more than he does his back teeth, or molars. These premolars, as well as the molars, have each a single ridge lengthwise. When the jaws come together, these ridges act like the blades of shears, cutting the food into pieces small enough to be swallowed whole. The dog's molars are not used so much for grinding as are man's.

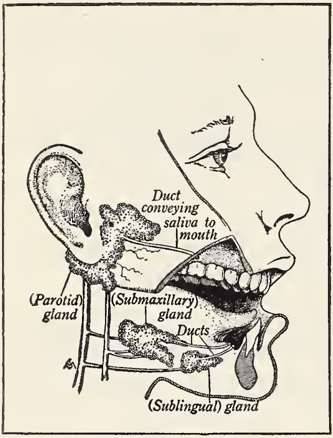


FIG. 196. What advantage is derived from having three pairs of salivary glands at different locations in the mouth, that would probably not be derived from having a single large gland?

The ancestors of the dog were flesh-eaters. Our ancestors included in their diet both meat and vegetables. It is to be expected, therefore, that our mouths must be equipped with different sorts of teeth from those of a dog in order to take care of the difference in diet. Our incisors are like chisels to cut the food. The canine teeth are useful in tearing tough foods and in breaking up the food in the mouth. The premolars and the molars are used in grinding the food.[2]

Digestion in the mouth. Saliva is a basic, or alkaline, substance secreted by three sets of glands (Fig. 196). Two of these glands are under the tongue (the sublingual glands); two are on the inner sides of the lower jaw, one on each side (the submaxillary glands); and two are just in front of the ears, one in front of each ear (the parotid glands). The saliva manufactured by these glands is poured into the mouth through ducts, or small tubes. During the process of chewing, the amount of saliva which these six glands pour into the mouth is increased and is mixed with the food as it is ground. Human saliva contains an enzyme, ptyalin.

[1] The premolars are often but incorrectly called bicuspids.

[2] TO THE TEACHER. If it seems desirable to consider at this point the hygiene of the teeth, that material will be found in Chapter XXIV.

*Saliva serves three functions: (1) It softens and moistens the food so that it can be swallowed and so that it will pass down the esophagus. (2) It dissolves dry and solid food so that some of this food in solution finds its way into little pits which are called the taste buds and which are located in the tongue. The flavor of the food, if it is pleasant, causes a more plentiful flow of digestive juices in the stomach. (3) The third function of saliva can be discovered by a simple experiment:

Experiment 65. What changes does saliva bring about in starch? Put into your mouth a little cornstarch. Can you note any change in the flavor of the food after it has been in the mouth a short time (few seconds)? Now remove the starch and the saliva, placing part in each of two test tubes. Put a little fresh starch mixed with a little warm water into another test tube for a control. Test the contents of the first test tube for starch (p. 78) and of the second for sugar (p. 265). Test the control likewise for sugar. What chemical change has the saliva effected in the starch? Can you state the third function of saliva? This effect of saliva on starch is due to the enzyme ptyalin.

Exercise on scientific method (isolating the experimental factor and using controls). What conditions or factors were the same in all three test tubes? What factor was different between the test tubes containing starch and saliva and the control? Why was the control necessary in this experiment?

Self-test on Problem XIV–C. **1.** A *man* uses his premolars chiefly for cutting the food into pieces, which he can then swallow without chewing.

2. Digestion, for *dogs*, begins in the mouth.

3. The three sets of glands which manufacture saliva in the human mouth are located __(?)__, __(?)__, and __(?)__.

4. Man grinds food with his *canine* teeth.

5. The three functions of saliva are __(?)__, __(?)__, and __(?)__.

Problem XIV–D · How is Digestion Carried On after the Food Leaves the Mouth?

The throat and esophagus. Swallowing is started by the action of the tongue. It presses against the teeth in front, then arches up against the hard palate in the roof of the mouth, thus pushing the food backward and forcing it into the throat. Here muscles

force the food downward, and at the same time the action of other muscles closes the openings into the nose and into the windpipe (trachea) (Fig. 197). These are involuntary muscles; that is, they cannot be controlled by the will. No matter how strongly one might wish to prevent their action, he could not do so. If the windpipe were to remain open when the food descended, food might enter it, causing the person to choke and strangle in an effort to force the food out. The food passes over the closed windpipe into the esophagus. Like the mouth and throat, the esophagus is lined with mucous membrane in which are an enormous number of tiny glands that secrete a special fluid, called mucus, which gives a slippery coating to the smooth surface of the esophagus.

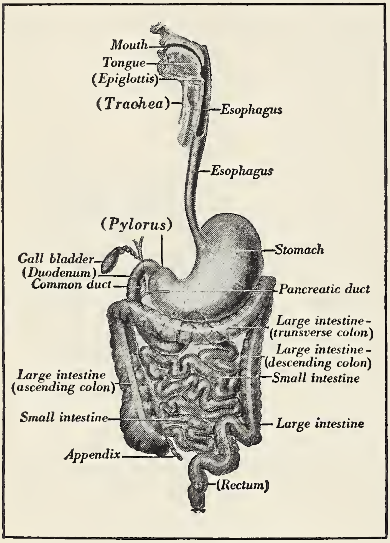


FIG. 197. Diagram of the human alimentary canal. Food within the alimentary canal is not considered to be within the body. Explain

The esophagus has two sets of muscles, one set running lengthwise and the other in rings around it. These sets of muscles alternately contract and relax in such a way that a series of wavelike movements pass down the esophagus. These movements force the food downward in much the same way as an object might be forced downward through a rubber hose if a metal ring somewhat smaller than the hose and just behind the object were pulled downward. These rhythmic[1] wavelike contractions which proceed down the esophagus, one after another, are known as peri-

[1] *Rhythmic* (rith'mik): having to do with rhythm. *Rhythm* (rithm): a series of regular movements or beats.

staltic waves and together constitute peristalsis. Peristalsis occurs throughout the length of the alimentary canal, or food tube.

No digestion takes place in the esophagus, except that the enzyme ptyalin from the saliva may continue to convert starch into sugar. No enzymes are secreted in the esophagus.

Digestion in the stomach. ***Experiment 66.*** Which is more effective in digesting protein: water, hydrochloric acid, pepsin, or a combination of water, pepsin, and hydrochloric acid? Into each of four test tubes place an equal small quantity of the white of hard-boiled egg. To the first test tube add water enough to fill the test tube about a fourth full. Dissolve pepsin in water and add to the contents of the second tube. Into the third test tube pour water to which you have added a few drops of hydrochloric acid. To the fourth add some of the solution of pepsin in water to which you have added also a few drops of hydrochloric acid. Have the liquids at the same level in all four tubes. Place all four test tubes side by side in some place where they will keep warm but will not become hot. Examine the contents of the tubes every hour or so during the day and again the following day. Summarize the results of the experiment. Answer in a brief paragraph the question asked at the beginning of this experiment.

*The lower end of the esophagus expands to form the stomach, a baglike organ in which the food is held while it undergoes further digestive action (Fig. 198). The digestive processes of the stomach include both physical and chemical changes. The stomach is always full. It never contains any empty space, because it expands when food enters it and contracts into loose folds like an empty pouch as the food is digested. Soon after food enters, peristalsis begins, that is, the rhythmic contractions start at the middle of the stomach and proceed to the lower end (the pylorus, Fig. 197). Digestion by the gastric juice in the stomach then proceeds mostly in the lower part. The food remains stored in the upper part, moving down slowly to take the place of the food which becomes liquefied[1] and passes out of the stomach. The digestion of starch by the ptyalin of the saliva continues in the upper end so long as the food remains alkaline. When it reaches the middle of the stomach and becomes mixed with the acid in the gastric juice, the digestion of starch ceases.

[1] *Liquefy* (lik′wi fy): to change to a liquid.

U. S. Department of the Interior

FIG. 198. Antelope at Wind Cave National Park, Hot Springs, South Dakota. The stomach of the cow, the deer, the sheep, the goat, the antelope, and the ox has four compartments. The food is received in the first compartment (the rumen). Later, when the animal is resting, this food is returned, a "cud" at a time, is chewed thoroughly, and then passes in turn through the three digestive compartments. How does this digestive adaptation help the animal to survive?

If one were to examine the interior of the stomach, he would see innumerable small pits which mark the mouths of tubelike glands. It is estimated that the stomach contains more than two million of these glands. These are the gastric glands, of which there are several kinds. Each kind secretes a substance necessary to digestion. All these secretions together make up the gastric juice. The gastric juice contains four important substances: hydrochloric acid and three enzymes (pepsin, rennin, and gastric lipase).

The hydrochloric acid performs several functions, among which are these: (1) it softens tissues of the food; (2) it kills bacteria of decay and therefore stops decay of the food; (3) it makes the protein ready for further digestive action (Fig. 199).

Each enzyme has a special function. One (pepsin) changes the proteins into simpler substances that are soluble in water. The second (rennin) attacks milk, causing it to curdle. The curdling of milk is a necessary step in its digestion. This curdling takes place readily at the normal body temperature, but takes place

more slowly at lower temperatures. The third enzyme (lipase) attacks the fats to a slight extent, thus beginning their digestion.

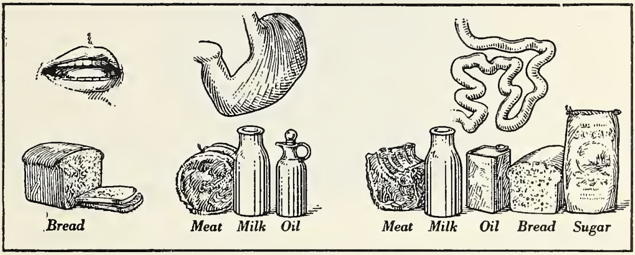


Fig. 199. This picture indicates food digested in the mouth, the stomach, and the intestine. Name the classes of energy foods digested in each of these organs

Because of the mechanical and the chemical action the food in the lower end of the stomach is slowly changed into liquid form. At the extreme end of the stomach there is an opening (pylorus) which is regulated by a ring of muscle. This muscle relaxes at intervals. As often as it does so, the peristaltic movements, which are occurring regularly, force a little of the liquefied food (called chyme) through the pylorus into the small intestine. The food, although liquid, is not yet completely digested. Only part of it is ready to be absorbed by the body. The rest must undergo further chemical changes in the small intestine.

Digestion in the small intestine. ***Experiment 67.*** Which is more effective in making fat into an emulsion[1]: water, some alkali, such as lye or ammonia, or some acid, such as vinegar or lemon juice? Put into each of three test tubes a half-dozen drops of olive oil, corn oil, or cottonseed oil. To the first add warm water. To the second add warm water in which a little lye or ammonia has been dissolved. To the third add warm water to which a little vinegar or lemon juice has been added. Have equal amounts of liquid in all three test tubes. Allow all three test tubes to stand side by side. Shake the contents of the test tubes from time to time. After two days examine the contents of all three test tubes. Answer with a complete statement the question asked at the beginning of this experiment.

[1] *Emulsion* (e mul′shun): a liquid containing fat distributed all through it in very fine drops.

Experiment 68. What is the action of pancreatic juice on emulsified fat protein, and starch? Make some artificial pancreatic juice by adding to 100 cubic centimeters of warm water 1 gram of commercial pancreatin and 2 grams of baking soda. Into each of two test tubes put a few drops of the oil which you emulsified, that is, which you made into an emulsion in Experiment 67. Into each of two other test tubes put a small amount of finely divided white of egg. Into each of two more put a pinch of starch. To the first test tube in each pair add the pancreatic juice and to the second tube of each pair add warm water. Put all six test tubes together in a warm place (70°–80° F.) for two hours. At the end of that time compare the appearance of each pair of test tubes. Summarize the results of your experiment in a few complete sentences.

Exercise on scientific method (using controls and isolating the experimental factor). Why was each test tube in Experiments 67 and 68 a control for the others? What substance was common to all the test tubes in each experiment? How many factors or conditions were the same for all test tubes in each experiment? What single factor was different in the test tubes in each experiment? This was the experimental factor.

*The small intestine is the portion of the alimentary canal, about twenty feet long, which is between the lower end (pyloric orifice) of the stomach and the beginning of the large intestine (Fig. 197). The small intestine serves two important functions: (1) to complete the digestion of all the nutrients; (2) to absorb the digested foods through its walls into the circulatory system. Its great length, its thin walls, and certain structures (the villi) make possible the absorption of digested food.

Partly digested food (chyme) from the stomach is subjected to the action of three distinct digestive juices in the small intestine: the pancreatic juice, the bile, and the intestinal juice. The pancreatic juice and the bile enter together at a point three or four inches from the beginning of the small intestine. The intestinal juice is produced by an enormous number of small glands in the walls of the small intestine.

The pancreas is a gland somewhat similar to the salivary glands. It is six to eight inches long, two and a half inches wide, and about an inch thick. It lies just behind the stomach and a little below it (Fig. 200). It produces three enzymes: (1) One (amylase) changes into sugars all the starch which has not already been

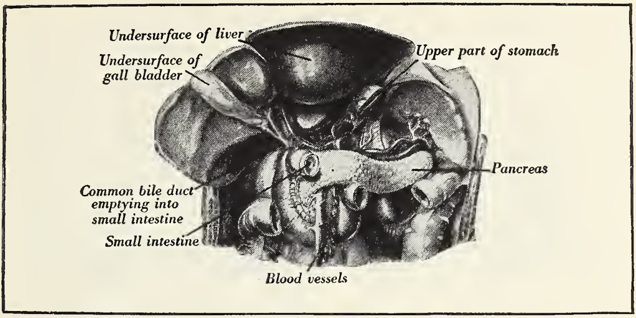


Fig. 200. Some digestive glands. The liver has been raised to show the pancreas and the gall bladder with the bile duct. Note that the stomach, which has been removed, was just in front of the pancreas. What are the functions of the pancreas?

digested by the saliva. (2) Another (trypsin) changes into amino acids the proteins which have escaped the action of pepsin in the gastric juice of the stomach and completes the digestion of those which have been partly digested by the gastric juice. (3) The third (lipase) acts upon the fats (changing them to fatty acids and glycerol). Before they can be completely digested, however, the fats must be changed to an emulsion (see Experiment 67).

The bile is secreted in the cells of the liver, which is the largest gland in the body. Bile is constantly passing through the bile duct into the small intestine, but is most abundant about eight hours after a meal is eaten. It is not a digestive juice in the same sense as saliva, gastric juice, and pancreatic juice, because it contains no enzyme. Nevertheless it increases by several times the speed with which the pancreatic enzyme (lipase) digests the fats. It also helps in the absorption by the body of the products of fat digestion.

Bile is unique in being both a necessary secretion and at the same time to a considerable extent a waste product, since it contains substances thrown out by the liver. Excess bile is stored in the gall bladder, from which it is poured when additional quantities are needed. Yet the function of the gall bladder is not clearly understood, because men and some of the other higher

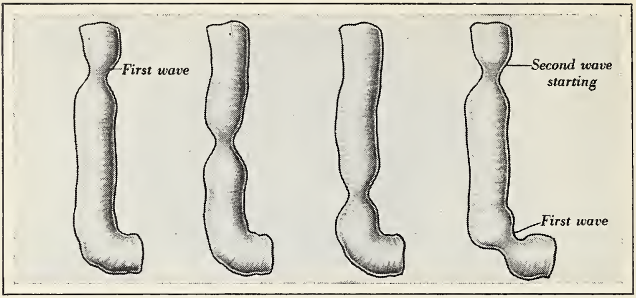


FIG. 201. Using this diagram, can you explain the action of peristalsis in the intestine?

animals not only have been able to live after the gall bladder has been removed, but have not apparently suffered from its loss.

The intestinal juice has four enzymes. One of these (erepsin) completes the digestion of proteins, which is begun by the gastric juice (pepsin) and carried on by one of the enzymes in the pancreatic juice (trypsin). The other three (maltase, invertase or sucrase, and lactase) complete the digestion of all the carbohydrates, except cellulose, into sugars which the body is able to absorb.

Action of the small intestine. The digesting food is made to pass through the small intestine as the result chiefly of two separate movements. The first is peristalsis, similar to that of the esophagus and the stomach. The peristaltic movements beginning at the upper portion of the small intestine force the food downward, making room for more food (chyme) to be discharged from the stomach. In the small intestine, however, the peristaltic waves do not follow one another in rapid succession, as they do in the lower part of the stomach (Fig. 201). Instead, after the movement has forced the food onward somewhat, the peristalsis stops. Immediately the second movement begins. In this movement rings of muscle at equal distances apart contract, causing the intestine to look somewhat as a rubber hose would if strings were tied fairly tightly around it at intervals of about two inches. After from about three to ten seconds these rings of muscle relax and another set midway between the rings of the first set contract,

making the intestine look as it did before, except that the bulges and the contractions have now exchanged places. After a few

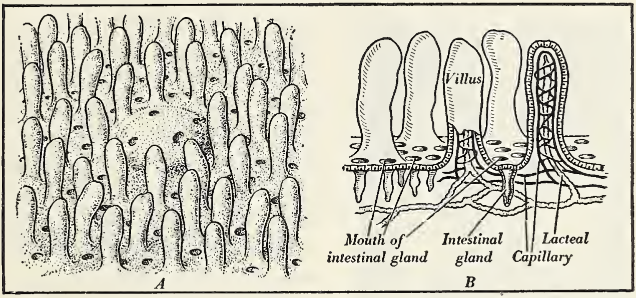


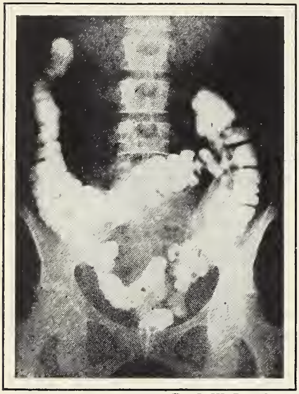
FIG. 202. The villi of the small intestine. Would absorption be more or less rapid and complete if each villus were a pit like an intestinal gland?

seconds these second rings relax, and the first contract again. By this motion not only is the food mixed more thoroughly with the digestive juices, but also fresh portions of the digested food are constantly being pressed against the absorbing surfaces of the intestine. In some parts of the small intestine the food may remain for forty-five minutes in one place, being kneaded by the motions just described, before another peristaltic movement forces it onward.

About four and one half hours are required for the first food of a meal to pass entirely through the small intestine. So long a time is necessary in order to give ample opportunity for the food to be completely digested and for absorption to take place. The structure of the intestine is such as to cause food to pass through it slowly. Throughout most of its length it has hundreds of ridges which run most of the way around it. These ridges delay the food in its progress, and in addition they furnish more surface both for secreting intestinal juice and for absorbing digested food.

***The absorbing surfaces of the small intestine.** The inside surface of the small intestine is not smooth. If it were examined with a microscope, it would look much like a length of velvet arranged in many small parallel folds. Every portion of the surface of the intestine is covered with villi (Fig. 202). These are

about one fiftieth of an inch or slightly more in length. Here and there in the sides of the villi are cells which secrete and discharge mucus into the intestine, but the chief function of the villi is to absorb the digested food. The digested food enters the villi partly by the process of osmosis. It is distributed within the villi partly by the processes of diffusion and imbibition. But these processes alone will not account for the rapid absorption. It is believed that the cells themselves cause the absorption to be more rapid by some means as yet unknown.



Dr. S. W. Donaldson

Fig. 203. X-ray photograph of the large intestine. What structures are shown here which protect the lower intestines?

The final products from the digestion of carbohydrates and proteins pass into the network of blood vessels in the villi. The fats do not pass directly into the blood, but enter another tube (lacteal, Fig. 217, p. 327) in the interior of each villus. How these digested foods are circulated through the body will be explained in the next chapter.

The large intestine. The large intestine (Fig. 203) has three major functions: (1) to serve as a place of temporary storage for food wastes; (2) to absorb water from the food wastes; (3) to absorb digested food remaining after its passage through the small intestine. About thirteen or fourteen hours are required for the food to travel through the large intestine, a distance of about five feet. The materials are forced through it by peristalsis occurring for a few seconds with intervals of several hours between the brief periods of peristaltic movements. The materials which finally are eliminated from the body consist of the part of the food which cannot be digested, together with some undigested food, bacteria, and waste products produced within the body.[1]

[1] To the Teacher. If it seems desirable to consider the hygiene of digestion at this point, this material will be found in Chapter XXIV.

Bacterial digestion. Bacteria in enormous numbers live in the alimentary canal. In the upper and middle parts of the small intestine these bacteria may feed upon the carbohydrates, producing chiefly carbon dioxide and acid (lactic). This bacterial action is called *fermentation.* If one is normally healthy, this fermentation is not harmful. The bacteria may even do some good in converting cellulose into forms which the body can absorb. If the bacterial action is too great, however, the acids produced irritate the walls of the intestine and cause diarrhea. In the lower end of the small intestine and in the large intestine the bacteria feed upon the waste nitrogen compounds, sometimes producing poisons which are absorbed by the blood.

Self-test on Problem XIV–D. **1.** Food is forced along through the alimentary canal by means of rhythmic waves called *protoplasmic* waves.

2. The enzyme in saliva changes *protein* to *starch.*

3. The three functions which are performed by the hydrochloric acid in the stomach are __(?)__, __(?)__, and __(?)__.

4. The gastric enzymes start the digestion of *starch* and *proteins.*

5. The two functions of the small intestine are __(?)__ and __(?)__.

6. Bile is produced in the *liver.*

7. A large digestive gland, the *liver,* pours into the small intestine enzymes which carry toward completion the digestion of carbohydrates, proteins, and fats.

8. The intestinal juice completes the digestion of *fats* and of all *carbohydrates* except cellulose.

9. Poisons are sometimes produced in the intestines by the action of *bacteria.*

10. The digested food is absorbed in the *small* intestine by the *villi.*

11. The three functions of the large intestine are __(?)__, __(?)__, and __(?)__.

Self-test on Biological Principles. **1.** How is division of labor illustrated by digestion in the sponge but not in *Amœba* or *Paramecium*?

2. From a study of the preceding sections choose the facts which you would use to illustrate this principle of biology: "Increase in complexity of structure goes hand in hand with division of labor."

3. How is division of labor illustrated by enzymes?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Considering the fact that pancreatic juice acts upon starch, should you expect it to be acid or alkaline? Why?

2. Are the intestinal bacteria parasites in the same sense as the mistletoe (Fig. 9, p. 19)?

3. Trace the digestion of a ham sandwich and a glass of milk, naming the organs through which the food passes while being digested and describing the changes which occur.

4. For what reason might it be more healthful to eat warm food rather than cold food? Why should not babies drink ice-cold milk?

5. One stops breathing when one swallows. Can you see an advantage in so doing?

6. In general, the plant-eating chordates have longer intestines than have meat-eating animals. What reasons can you give to account for this fact?

Exercise on Scientific Method. **1. Making Inferences.** *a.*[1] Two live frogs each weighing 60 grams are selected and two small crayfish each weighing 20 grams are also selected. One crayfish is fed to each frog. The frogs are kept at 60° F. for three hours and then one (1) is put in the ice chest at 40° F. and the other (2) is kept at 80° F. in a warm room. What differences will be found in the state of digestion of the crayfish at the end of 48 hours, and why?

b.[1] Protozoa are found in the intestines of certain termites (white ants). These Protozoa can be removed from the intestine without causing any physical injury to the termite. The Protozoa feed on wood pulp which is eaten by the termites. Thirty-six of these termites were selected for an experiment. The Protozoa were removed from the intestines of eighteen of them. These termites ate wood pulp but continued to lose weight, became inactive, and soon died. The other eighteen termites were observed during the same period. They lost no weight, and were active throughout the period of observation. What is the most reasonable and most complete interpretation which you can give of this experiment?

2. Inventing Experiments. Devise an experiment which will show that saliva acts on starch but not on protein.

Special Reports. **1.** Fig. 197 shows the location of the vermiform appendix. What is the nature of the disease appendicitis? How is it treated? (Consult your family physician for information.)

2. What is the nature of commercial rennin (rennet)? What is its relation to the cheese-making industry?

[1] Included by permission of Dr. R. W. Tyler.

Chapter XV · Transportation and Use of Energy and Necessary Materials within an Organism (Circulation and Assimilation)

Questions this Chapter Answers

What are the functions of a circulatory system?
What are some important facts about circulation in plants?
How do circulatory systems of animals differ?
What are the structures and the functions of the circulatory system in man?
What are the characteristics of the lymphatic system?
What is the effect of alcohol upon the circulation?
What are the nature and the functions of the blood?
What is the relation of circulation to health?
How is food used in the cells?

Problem XV–A · What are Some Important General Facts about Circulation in Plants and Animals?

Cells somewhat like people. In the earliest pioneer days in this country the problem of securing food was largely an individual matter. Hunters and trappers went off into the wilderness, remaining by themselves sometimes for many months (Fig. 204). Families lived miles apart and often saw no members of other families for long periods of time. Every hunter and trapper had to secure his own food, chiefly and sometimes wholly by his own efforts. Every family had to depend upon the activities of its own members for its food supply, and practically every member had some share in these activities. Even in the early settlements where a number of families clustered together for protection, every family was to a large extent independent of the rest and provided its own supply of food with little help from its neighbors.

The problem of securing food is a very different one in our modern great cities. Here few people are engaged in food production. No cities would be possible if every person or every family had to raise its own supplies. The people are gathered together in

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FIG. 204. In the Olympia Peninsula, Washington. What kinds of food must this man largely secure for himself and what kinds can he carry with him?

great numbers to engage in all sorts of useful and necessary work most of which has nothing whatever to do with food manufacture. Yet everyone must be fed. The city people must therefore secure their food supplies from other people whose chief business is the production of food and who may live long distances away.

With respect to their feeding problems, the individual cells of plants and animals are somewhat like people. The comparison, however, cannot be carried too far. Every one-celled animal or plant, like the solitary hunter or trapper, must secure its own supply of food. The simpler organisms, consisting of relatively few cells, may be roughly compared to the pioneer family. The cells which do not capture food must secure digested food from the cells which do. The cells in the higher plants and animals may be compared to the people in a city. Only a relatively small proportion of the entire number of cells in the organism are engaged in digesting food. But every active cell in every part of the organism must nevertheless secure some of this digested food.

The circulatory system an irrigation system. Water is essential for growth and replacement of protoplasm in every living cell. No animal or plant, therefore, can carry on its normal life activities if it is dry. It is true that the lowest organisms, such as bacteria and Protozoa, can dry out and still live for a considerable time. Yet during this period they are in a resting stage and are carrying on few of their normal activities and these only at a reduced rate. They will resume these activities only when they are again in water, milk, blood, or some other fluid which is chiefly water.

The simple plants and animals, consisting of relatively few cells, must therefore live either in water or in some other fluid, and must be so constructed that the fluid in which they live bathes a considerable number of their cells. In the higher animals every living cell must be bathed in fluid, just as is the amœba or other simple one-celled animals. No complex water animals, such as fish, and no higher land plants and animals ever have come to exist upon the earth without developing some means by which every living cell in their bodies could be bathed in fluid. The circulatory systems of plants and animals perform this necessary function.

***The circulatory system a food-transportation system.** In the simpler organisms either every cell is able to digest at least part of its needed food, or it is close enough to other cells which digest food to be able easily to secure from them what it needs. No circulatory system is necessary, therefore, in simple plants and animals. In the complex organisms, however, most of the cells are too far from the source of digested food to secure it by simple means. Some sort of circulatory system is therefore necessary in order to carry water, digested foods, oxygen, and other needed materials to every cell. We may think of a complex organism, then, as if it were a huge colony of separate cells each of which lives its life more or less separately but each of which depends upon the circulatory system to bring necessary supplies to it.

***Other functions of the circulatory system.** The transporting of energy and other needed supplies to every cell is only one of several important functions of the circulatory system. It must also act as a sewer system to carry off the wastes which are ex-

creted[1] by every living cell. It must carry to every part of the higher animals and even of many of the lower forms certain amœboid[2] cells which protect an organism by destroying disease germs. In the higher animals it must also carry certain substances called hormones, which are manufactured by special glands and which regulate growth and other bodily activities. In the higher animals, too, it must act as a heat-distributing system, since the body must be kept at a fairly constant temperature. For normal adult human beings this temperature varies from about 98.2° F. to 99.4° F. Heat must therefore be carried from parts, such as the muscles, which produce too much heat, to other parts which do not produce enough.

It must be kept in mind, however, that the functions of circulation are not separate processes, but that all are being carried on together all the time and in all parts of an organism (Fig. 205). Thus cells are taking energy, water, minerals, oxygen, and hormones from the blood, and at the same time they are putting into it carbon dioxide and other waste products. The blood may be delivering extra heat energy along with needed supplies, or it may be taking away heat along with the wastes. The amœboid cells may at any time be leaving the blood and entering tissues where they are needed to fight germs, or they may be passing out of tissues where they are no longer needed, to travel in the blood stream to other parts which are being attacked.

In the preceding chapter a study was made of digestion in various plants and animals in order to show that more complex organisms must have more complex digestive systems than simpler organisms. A similar brief study will now be made of the means by which energy and necessary materials are distributed. Waste disposal and other functions of circulation will be discussed in later chapters.

Self-test on Problem XV–A. **1.** In *all* organisms each cell must digest its own food.

2. A *living cell* to survive must be bathed in water or some other fluid.

3. Which of the following are functions of the circulatory system of a complex organism: (1) to carry oxygen to every cell; (2) to carry heat

[1] *Excrete* (ex kreet'): to separate out and get rid of waste products.
[2] *Amœboid* (a me'boid): looking like and acting like an amœba.

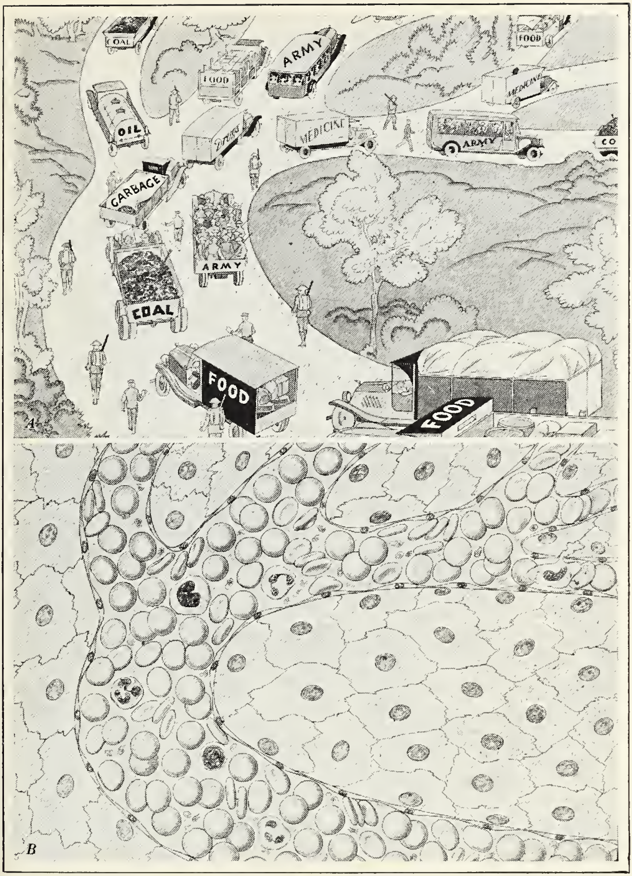


FIG. 205. *A* represents a crowded one-way highway and *B* a small section of a capillary or very small blood vessel. *A* presents several functions of the circulatory system. What functions of the circulatory system *B* are represented in *A*? What functions cannot be represented? (From a drawing by Adrian J. Iorio)

energy from the parts where it is produced most rapidly to those where it is produced less rapidly; (3) to act as a sewer system; (4) to keep every cell bathed constantly in fluid; (5) to carry supplies of food energy to every cell; (6) to digest food which has not been digested in the intestines; (7) to cause the heart to beat?

4. What functions of the circulatory system are not named in 3?

Problem XV–B · What are the Important Structures of Plant and Animal Circulation and What are their Functions?

Circulation in the simpler plants. Digested foods and other needed materials pass into bacteria by osmosis. These materials are distributed throughout the protoplasm of the cell chiefly by diffusion, assisted to some extent, perhaps, by the movements of the plant.

Some of the mosses have rudimentary[1] circulatory systems, but no plants simpler than the mosses have special structures to assist in circulation. In nearly all these simpler plants circulation is accomplished by osmosis from cell to cell.

***Circulation in higher green plants.** Higher green plants have an extensive circulatory system called the vascular system. This system is necessary because the cells in the leaves and stems, where food is made, may be several hundred feet from the cells in the roots, which secure water and minerals. Certain cells, therefore, are concerned wholly with circulation. These form a continuous system (Fig. 206) which runs from the roots through the stem, branching thence to the limbs and to the separate leaves, and continuing through all the leaf veins. Another similar system parallel with the first carries liquids and dissolved food materials to all parts of the plant. The structures and the processes of circulation in plants are described in detail in Chapters V and VI.

Circulation in some of the simpler animals. The simpler animals, like the simpler plants, need no vascular, or circulatory, system. In Protozoa (Fig. 207, *A*) the process of diffusion and the movements of the animal are together sufficient to circulate the necessary materials through the one-celled body.

[1] *Rudimentary* (ru di ment'a ry): in the earliest stages of development.

With simple water animals, like the sponge (Fig. 207, *B*), digested food and other necessary materials pass from cell to cell by osmosis aided by certain amœboid cells which can move independently among the cells.

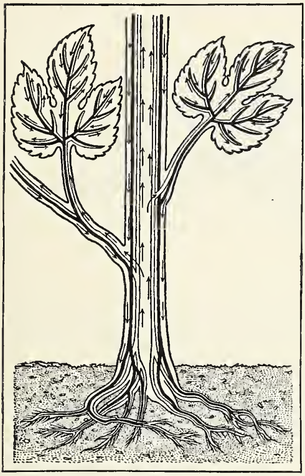


Fig. 206. Can you explain the process and describe the structures of circulation in monocots and dicots? (Consult Chapter VI)

In *Hydra* (Fig. 207, *C*) digested food passes by osmosis from the cells of the inner layer, which capture and digest food, to the cells of the outer layer, which do not. When the inner cells capture and digest more food than the animal immediately needs, this excess food is stored in the outer layer ready for future use.

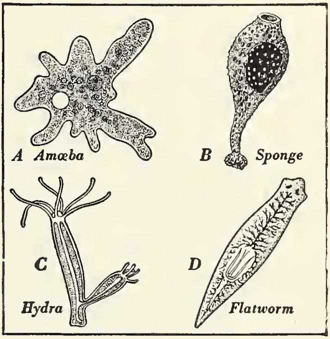


Fig. 207. In what respects is circulation in each of these animals more complex than that in the one that precedes it and less complex than that in the animal which follows it?

In some of the flatworms which are not parasites, digested food passes by osmosis through the walls of the intestinal trunks and the smaller branches (Fig. 207, *D*). These smaller branches lead into every part of the body. All the cells, therefore, are sufficiently close to the supply of digested food to be able to secure nourishment readily by osmosis.

Circulation in the grasshopper. In Chapter XIV the earthworm was discussed before the grasshopper, because the digestive system of the earthworm is more simple than that of the grasshopper. The

opposite is true with respect to circulation, although the grasshopper is in general a more complex organism than the earthworm.

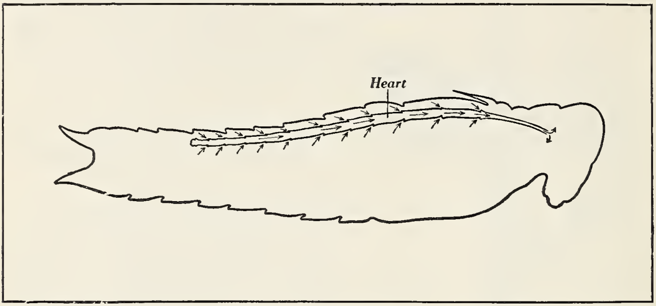


FIG. 208. The circulatory system of the grasshopper. In what respects is it more complex than that of any of the animals in Fig. 207?

Unlike the simpler animals just described, the grasshopper and each of the animals which will be discussed in the rest of this chapter have circulatory systems of some sort. In such circulatory systems the blood follows a definite path to the various parts of the body and returns by a different path to its starting point.

The circulatory system of the grasshopper is an example of an open vascular system. It represents the second type of circulatory system discussed in this chapter. The first is that found in the higher plants. This consists of a number of tubes end to end. The tubes make a complete system, but each is separated by a membrane from the one which precedes and follows it. The open vascular system, such as that found in the grasshopper and in insects in general, is one in which the blood makes part of its journey through tubes and the rest through irregular spaces. These tubes, unlike the vascular bundles of plants, have open ends. The third type is the closed vascular system, which is represented by the circulatory systems of the higher animals, including man. This system is one in which the blood makes its entire journey through continuous tubes.

The grasshopper has a single blood vessel extending down the middle of the back (Fig 208). The rest of the system is merely a

body cavity, in which the colorless blood flows about, bathing the various organs. The blood vessel is a crude sort of heart. It

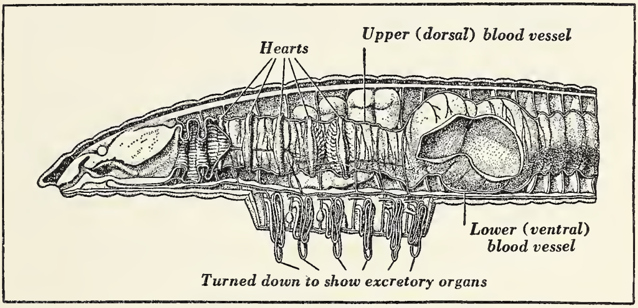


Fig. 209. In what respects is the circulatory system of the earthworm more complex than that of the grasshopper and the crayfish?

pulsates, or beats, forcing the blood out at the front (anterior) end into the body cavity. Narrow openings (ostia) along the sides of the vessel open inward when the vessel pulsates, permitting the blood to enter from the body cavity.

Circulation in the earthworm. The circulatory system of the earthworm is a closed system of blood vessels which go to every part of the body. Instead of only one heart, moreover, the earthworm has five pairs of hearts (Fig. 209). These hearts are very simple, each being scarcely more than an enlarged blood vessel equipped with valves. An upper (dorsal) main trunk and a lower (ventral) one run lengthwise in the animal. The hearts connect the upper main trunk, or tube, with the lower trunk. Peristaltic waves, passing from the rear to the front end in the upper main trunk, force blood into the hearts. The hearts pulsate, forcing the blood into the lower trunk, from which it flows into various branches. All the branches, however, lead back finally to the upper main trunk.

Circulation in the fish. The fish has a more complex circulatory system than that of any of the animals previously discussed. It has a two-chambered heart. From one chamber, the ventricle, the blood is pumped into the main artery, which has many branches.

These branches divide into finer and finer tubes, the smallest of which are the capillaries. The capillaries unite to form larger tubes, the veins. The blood returns through the veins to the second chamber of the heart, the auricle, which opens through a valve into the ventricle.

As the blood leaves the heart, it passes to the gills, where it receives oxygen and gets rid of carbon dioxide. The blood circulates through the body of the fish rather slowly. As a result there is not a very large supply of oxygen available to oxidize food and to release energy in the cells. Such energy as is released is needed chiefly to carry on movement and life processes. Relatively little appears in the form of heat. The temperature of the fish is, then, nearly the same as that of the surrounding water. Fish are therefore said to be cold-blooded animals.

Circulation in the frog. ***Experiment 69.*** How do the capillaries of a frog look, and how does the blood pass through the capillaries? Saturate a piece of absorbent cotton with water containing some ether and wrap the saturated cotton around a tadpole, or hold the cotton where a frog must breathe the ether fumes. When the animal has become quiet, place the tail of the tadpole or the web of the frog's foot under first the low-power objective and then the high-power objective of a compound microscope. Can you see the many branched capillaries? Can you see the larger blood vessels from which they branch (arteries) and those which they unite to form (veins)? Can you see the blood cells, or corpuscles, passing through the capillaries? Does the blood move more slowly or more rapidly in the capillaries than in the veins and arteries? Can you see any advantage in this change of speed? Are all the corpuscles of the same kind? Summarize the results of your observations in a paragraph or by means of diagrams.

The blood flow may be observed in the fin or tail of a goldfish or minnow if the fish is treated in the same way as the tadpole in this experiment or if a few drops of ether are put into the water in which the fish is swimming.

The circulation of the frog is more like that of the higher animals than is the circulation of the fish. The heart of a frog has three chambers, one ventricle, from which blood is pumped into the arteries, and two auricles, one on the right side and the other on the left, into which the blood passes after leaving the veins.

Circulation in a reptile. In the reptile the heart is more highly developed. It has three chambers, two auricles and a ventricle,

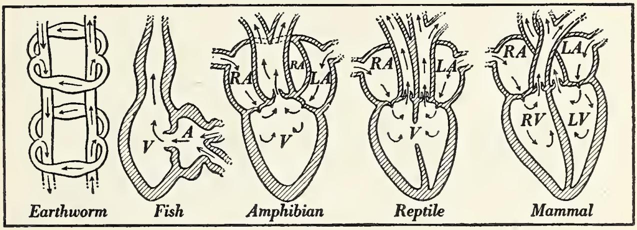


FIG. 210. In what respects is each heart more complex than the one preceding it?

like that of the frog, but, unlike the frog's heart, it has a wall of tissue which extends down the middle of the ventricle, almost separating it into two chambers.

Circulation in birds and in mammals. The bird is the lowest chordate, except the crocodile, which has a four-chambered heart. All the animals above the bird in the scale of life likewise have four-chambered hearts. Up to this point in the discussion each animal has had a somewhat more complex circulatory system than the animal which preceded it. In the vascular system of the bird, the dog, the elephant, man, or any other higher animal, however, there are the same kinds of blood vessels leading to and from the same kinds of organs. The chief differences are that some vascular systems are longer and more complex than others. Therefore, since, with respect to circulation, any one of the higher animals will represent the group as well as any other, the circulation in man will be described in detail in Problem XV–C.

***Summary of facts about circulation in plants and animals.** In the simplest plants and animals there is no need either for blood or for a special system of blood vessels, because every cell is sufficiently near the source of digested food and other needed materials so that it can secure these by osmosis. In every complex organism, however, a closed vascular system is necessary in order that every living cell in every part may be reached. The higher plants have closed vascular systems, but none of the plants has a heart or other organ corresponding to a heart.

In general the more complex the structure of animals, the more complex the circulatory system. Veins, arteries, and capillaries take the place of spaces or simple tubes. No heart exists in the lowest animals. Higher forms have crude hearts. Still more highly organized animals have more highly organized hearts. Thus there is a simple pulsating vessel in the earthworm and in the grasshopper, a two-chambered heart in the fish, a three-chambered heart in the frog, and a four-chambered heart in the bird and in the rest of the higher chordates, including man (Fig. 210).

Self-test on Problem XV–B. **1.** In simple plants liquids are circulated from cell to cell by the process of --(?)--.

2. The vascular system of *higher plants* consists of a series of separate tubes placed end to end.

3. In the *simpler animals* no circulatory system is necessary, because no cell is very far from the source of digested food.

4. The three types of circulatory system, which are represented respectively by the higher plants, the grasshopper, and man, are --(?)--, --(?)--, --(?)--.

5. Some animals — for example, *Hydra* — have *several* hearts.

6. The *higher* the animal, the less complex its circulatory system.

7. The lowest class of chordates in which the four-chambered heart is characteristic is the *mammals*.

Problem XV–C · What are the Structures of Human Circulation and What are their Functions?

The circulatory system in man. The circulatory system in man is composed of the heart, the arteries, the capillaries, the veins, and the lymphatics. The arteries, capillaries, and veins differ somewhat from one another; yet they are only different parts of the same continuous system of tubes which begins and ends at the heart. The wall of an artery consists of three layers (Fig. 211). The inside coat is an elastic membrane lined with thin flat cells. The middle coat is a thick layer of muscle and elastic fibers. The outer coat consists of bundles of supporting tissue and elastic fibers. As people become older, the walls of the arteries usually become less elastic. This condition is known as "hardening of the arteries."

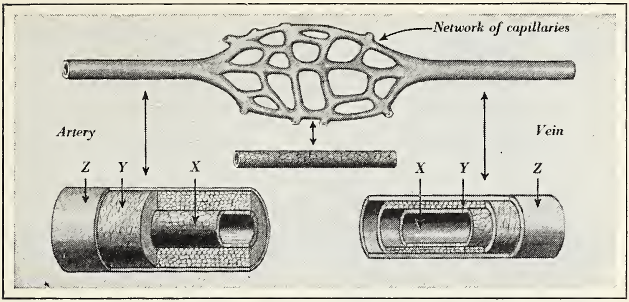


FIG. 211. Describe the differences in structure of these three blood vessels

*The capillaries join the small arteries with the small veins. Although the longer ones are only about as long as a dime is thick, they branch and rebranch to form a microscopic network. Capillaries have only one layer of cells, and this layer is the same as that which forms the inside lining of the arteries and veins. This single thin layer permits the passage of materials readily into and out of the capillaries.

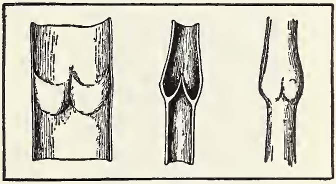


FIG. 212. What is the function of these valves in the veins?

The walls of the veins are composed of the same three layers as the walls of the arteries. The middle layer, however, is much thinner and contains a much smaller proportion of elastic tissue than the same layer of an artery wall. Within certain of the veins there are valves. These valves are like pouches (Fig. 212). If the blood tends to flow backward, these valves fill and close the passage. The dammed-up blood may then find its way through other tributary veins through which, were it not for the valves, little blood would be likely to flow. Valves are found especially in the vertical veins, where they aid the flow against gravity.

The lymphatic system. As the blood circulates rapidly through the blood vessels, the liquid portion, or plasma, is forced through

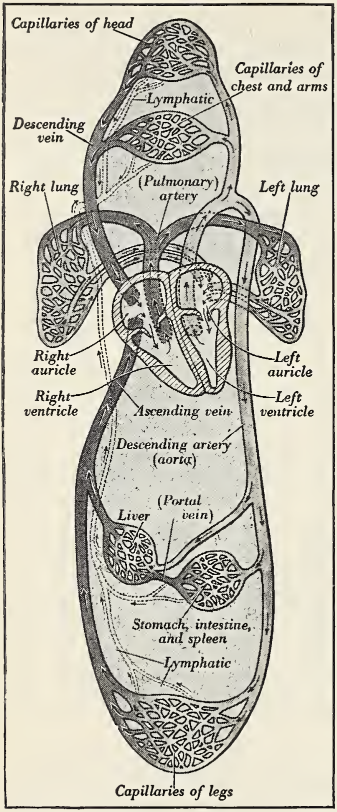


FIG. 213. The dotted lines represent the lymphatic system; the solid lines represent the circulatory system. Can you trace the circulation from any point in a blood vessel and back to the same point?

the walls of the capillaries by a combination of pressure in the arteries and osmotic pressure. It finds its way as tissue fluid, or lymph, into the minute tissue spaces between and around the cells, bathing all of them. From the tissue fluid, individual cells receive energy foods, oxygen, and all other materials which they need. Into the tissue fluid, at the same time, they deliver carbon dioxide and some other waste products. Thus the tissue fluid rapidly becomes very different from the plasma inside the blood vessels.

Some of the tissue fluid passes back through the walls of the blood vessels, but most of it does not. Consequently there needs to be some way in which the liquid lost from the blood vessels may be given back to them. This need is supplied by a second system, called the lymphatic system, which is closely associated with the circulatory system (Fig. 213). Plasma enters the tissue spaces faster than tissue fluid passes back into the capillaries. Therefore the tissue fluid is slowly forced from the spaces around the cells into small tubes which open from the tissue spaces. These tubes are called lymphatics. The tissue fluid after it enters them is called lymph. The smaller lymphatics lead into

larger ones, and these finally into tubes which empty into the veins of the neck. The lymph is forced or squeezed through the lymphatics chiefly by the movements of the muscles. Valves in the lymphatics similar to those in the veins keep the lymph flowing toward the points where it enters the blood stream.

At many points in the lymphatic system the tubes are enlarged to form glands. These are composed largely of fibrous[1] tissues surrounded by spaces. The main function of the lymph glands is to remove from the lymph harmful bacteria and solid impurities. The bacteria are destroyed by the white corpuscles. These collect in the spaces in the gland tissues and capture the bacteria from the lymph as it flows through the gland. Solid impurities, such as dust particles, are strained out of the lymph by the fibrous tissues. These solid impurities remain stored in the gland.

*__The heart.__ The human heart, like that of the other mammals, is a pear-shaped organ located in the middle of the body just behind the breast bone. It is attached to the inner wall of a double-walled bag of tissue (the pericardium). Between the two walls is a small quantity of fluid. This lessens the friction caused by the heartbeats. The heart is really two pumps, side by side, with the same middle wall serving both. Both sides act at the same time. Each pump consists of two chambers. The upper one, the auricle, receives the blood from the veins. The lower one, the ventricle, pumps it into the arteries. Heartbeat is caused by the action of the heart muscles. They contract, then relax, and after a brief period of rest repeat the action. Heartbeat is less frequent in adults than in children; in males than in females; in resting animals than in active ones.

The heart is a powerful organ. In forcing the blood through the blood vessels of a hundred-fifty-pound man in twenty-four hours, it does work equal to that done in carrying a hundred-fifty-pound man to the top of a hill about a quarter of a mile high.

*__How the blood circulates.__ The work of the heart and the blood vessels is more easily understood if one begins at some point in the system and follows the blood around and back to the same point. It must be kept in mind, however, that the blood is flowing through all parts of the circulatory system at the same time,

[1] *Fibrous* (fi'brus): made of fibers.

and that both sides of the heart work at the same time and in exactly the same way. Let us start with the right side of the heart, at the time of the brief rest period between beats. The muscles of the heart are now relaxed. Blood is being emptied from the large veins into the right auricle. Since the muscles are relaxed, the valve is open. Hence part of the blood falls through the valve into the right ventricle. When both the auricle and ventricle are nearly full, the auricle contracts, squeezing the blood out of it into the ventricle. The right ventricle then contracts, strongly forcing shut the valve between it and the right auricle and forcing the blood out into the pulmonary[1] artery leading to the lungs. As the blood passes through the capillaries of the lungs, there is an exchange of oxygen and carbon dioxide. Thus oxygen passes through the capillary walls from the lungs at the same time that carbon dioxide passes from the blood through the capillary walls into the lungs. The blood now flows from the lung capillaries into the pulmonary veins, which carry it back to the left auricle of the heart. The heart action just described is now exactly repeated on the left side. During the rest period, both auricle and ventricle fill with blood from the pulmonary veins. The auricle contracts first, forcing the blood into the ventricle. The ventricle then contracts, strongly forcing the blood into the large artery (aorta) leading out into the body (Fig. 214). This artery branches into smaller arteries, and these in turn into finer and finer branches, until finally these become the microscopic capillaries in all parts of the body.

*This point marks the end of the journey of the blood away from the heart and the beginning of its return journey. From the capillaries the blood flows into small veins. These unite into larger and larger veins. Finally these lead into the two large veins which pour the blood back into the right auricle of the heart. Valves at the openings of the arteries leaving the heart and at many places in the veins keep the blood flowing in a continuous stream (Fig. 212, p. 317).

Approximately one third of a minute is required for the blood to make a complete circuit through the most distant parts of the body and back to its starting point again.

[1] *Pulmonary* (pul′mo na ry): having to do with the lungs.

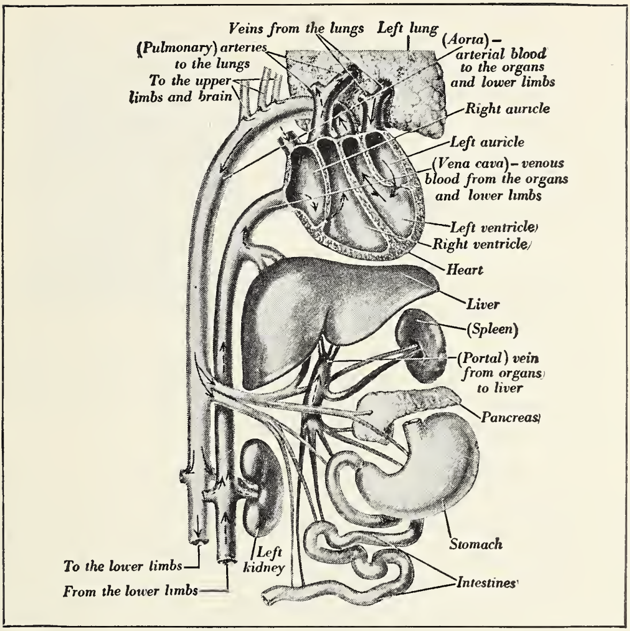


FIG. 214. Can you trace the blood to and from the various organs?[1]

Have you ever noticed how the speed of the current varies in different parts of a small stream of water? When the water passes through a narrow channel, it moves much more swiftly than when it spreads out over a broad bed. The speed of the blood current is similarly affected by the size of the blood vessels. When the blood leaves the heart in the large artery (aorta), it is moving swiftly. The more the arteries branch, the more paths there are for the blood to take, and the more space the blood must fill. Hence the more slowly it moves. Consequently, by the time it reaches the capillaries, it is moving slowly indeed. The reverse happens when the blood enters the veins on its way back to the

[1] From Meier and Meier's *Essentials of Biology*.

heart. As the many channels or veins come together into larger ones, the blood increases its speed.

The blood vessels are always full. Therefore when more blood is forced by the heart into the arteries, the elastic walls of the arteries are forced outward by the sudden extra supply of blood. This movement of the walls of the arteries travels along them as a pulse. The elastic nature of the walls, however, steadily resists and reduces the pulse, so that by the time the blood reaches the capillaries its flow is steady.

Experiment 70. Does the rate of the heartbeat vary under different conditions? Have some member of your class count the number of times your heart beats per minute while you lie down, again while you sit, and once more while you stand. In taking the pulse press the finger, not the thumb, against the artery in the wrist or the temple. Now exercise vigorously for a minute; then have your pulse taken again. State your conclusions in a few sentences.

Blood pressure. The pressure of the blood within the arteries varies with each individual as a result of meals, baths, emotion, violent exercise, whether he is sitting or standing, and other factors. It also varies greatly between each heartbeat and the brief rest period between beats. Normally the pressure for children is less than that for adults (Fig. 215). And the normal pressure for women and girls is somewhat less than that for men and boys. Sometimes old people whose arteries have hardened suffer a stroke (of apoplexy) immediately after a meal because the increased blood pressure has caused a blood vessel to burst.

Alcohol and the circulation. Upon drinking alcohol one's pulse is quickened as if stimulated. The apparent stimulation, however, is believed by certain authorities, as a result of careful investigation, to be due to the fact that alcohol has interfered with the nerves which control the heart and circulation. The result is a depressing, or narcotic, effect — the opposite of stimulation. Even when small doses are taken, the heart beats faster and the blood vessels in the skin are dilated more than normally. Because of the increased blood supply in the skin, one feels warm. But the loss of heat from the blood in the dilated blood vessels is rapid and great. While it is true that alcohol is to some extent oxidized in

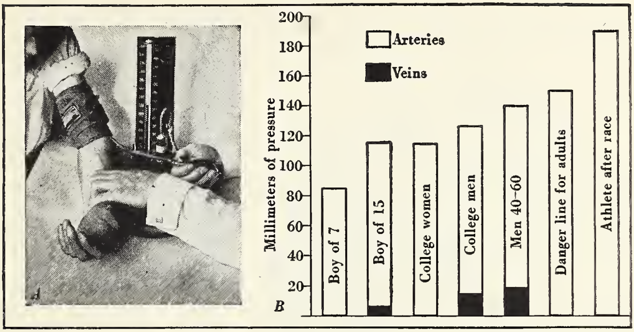


FIG. 215. *A*, taking blood pressure with a sphygmomanometer.[1] *B*, pressures in the arteries, and a few corresponding ones in the veins. The figure shows that the pressure in the arteries of a young man, at the instant his heart muscles contract and send forth the blood, is enough to hold up a column of mercury 126.5 millimeters high. Can you interpret the other columns in the graph? How do the pressures in the veins compare with those in the arteries?

the body to produce heat, nevertheless the gain from this oxidation is far less than the loss of heat from the skin. The result, therefore, is that drinking alcohol to keep warm soon leaves the person in far greater danger from cold than before.

Health and circulation. The same general habits which help to keep one healthy help to insure a healthy circulation. Exercise is especially important, since a primary function of exercise is forcing lymph through the lymphatic system. Fresh air, sunshine, recreation, plenty of good food, regular habits of elimination, and sufficient sleep and rest also have their values. There are, however, diseases of the heart and dangerous conditions of the blood or of the blood vessels which may exist for a long time before becoming sufficiently serious to attract attention. By the time they are detected, they may have become so aggravated that little help can be given the sufferer. It is a wise policy, therefore, for everybody to have a complete health examination by a physician once a year.

[1] *Sphygmomanometer* (sfig'mo ma nom'e ter): an instrument for measuring the pressure of the blood in an artery.

Self-test on Problem XV–C. **1.** The arteries, capillaries, and veins form one *continuous* system of tubes connecting with the *heart.*

2. The walls of the *capillaries* need to be stronger than those of the veins and the *arteries.*

3. The fluid which bathes our individual cells is the *blood.*

4. The lymph, collected from all parts of the body, is carried by the *circulatory* system and is emptied into veins in the *chest.*

5. Lymphatic glands function in purifying the *blood* of bacteria and solid particles.

6. The human *heart* is a double pump.

7. Name the blood vessels through which the blood passes in flowing from a capillary in your middle finger through the circulatory system and back to the same capillary. Name the various parts of the circulatory system in the order in which the blood would reach them.

Problem XV–D · What is the Nature of Human Blood and How does it Perform its Functions?

The blood. There are about six quarts of blood in a man of ordinary size. This is distributed in such a way that about one fourth is always in the heart, lungs, arteries, and veins, one fourth in the liver, one fourth in the muscles, and one fourth in all the other organs. One can gain some valuable information concerning the nature of the blood by a simple experiment.

Experiment 71. What is the nature of human blood? Carefully moisten a bit of absorbent cotton in alcohol; then rub the alcohol over the end of a finger in order to kill all germs upon the skin. Sterilize[1] a small needle by dipping it into alcohol or by holding it for an instant in a flame. Squeeze the blood toward the end of the finger. Then stick the needle into the finger and extract a small drop of blood. Make a microscope slide of this and observe it through first the low-power and then the high-power objective of the microscope. What is the color of the blood as seen through the microscope? Are all parts colored? Do you observe any solid bodies in the liquid? Are these all alike? In order to answer this last question you may need to examine several samples of blood. Summarize your observations in a paragraph accompanied by such sketches as are necessary in order to make clear your findings.

[1] *Sterilize* (ster'i liz): to destroy all germs in a space, in a substance, or upon a surface.

The plasma. The blood consists of about one third corpuscles, which are special kinds of cells, and two thirds plasma. The plasma is a clear, slightly yellow transparent fluid. It is about 90 per cent water, with the remaining 10 per cent chiefly organic compounds in solution. These dissolved compounds consist of (1) a number of special blood proteins; (2) the nutrient, or energy, substances, in the form of sugar, amino acids, and fats which have passed into the blood stream from the villi of the small intestine; (3) various mineral salts which likewise have passed into the blood from the villi; (4) oxygen, carbon dioxide, and nitrogen; (5) waste products other than carbon dioxide; (6) hormones from various glands; (7) certain substances which help the body to resist disease.

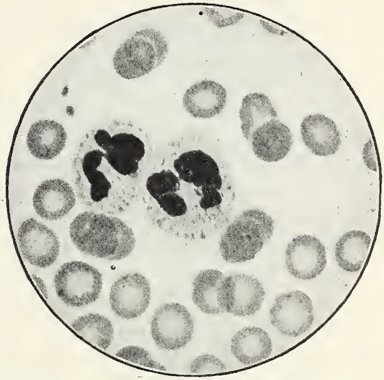


Fig. 216. Cells of human blood photographed through a microscope. Are any types of cells in Fig. 205, p. 309, which are not shown here?

The blood cells. **The red corpuscles.* Blood corpuscles are of three kinds: red corpuscles, white corpuscles, and blood plates. The red corpuscles of man, except when they are first formed, have no nuclei (Fig. 216). However, in some of the lower organisms — for example, the frog — these corpuscles have nuclei. Red corpuscles are constantly being formed in certain spongy tissue in the red marrow of certain bones. The red corpuscle is not really red but is a straw color. It gets its color from an iron compound called hemoglobin, which is able to carry oxygen and carbon dioxide. Oxygen combined with the hemoglobin gives the blood a deep-red color. Carbon dioxide combined with the hemoglobin gives the blood a darker, brownish tint. When the red corpuscles become worn out, they are broken up, chiefly, it is believed, in the spleen and the liver (Fig. 214, p. 321). The iron compound is kept in the body, but the remainder is excreted as part of the bile.

Anemia is a diseased condition which may result from several causes: (1) the body may not have enough red corpuscles; (2) the red corpuscles may not have in them enough hemoglobin to carry a sufficient supply of oxygen to the cells of the body; or (3) too many red corpuscles may be combined with some substance such as carbon monoxide, so that there are not enough uncombined corpuscles left to carry sufficient oxygen to the cells. The anemia patient is likely to be pale and to become easily tired. In all cases where this disease is suspected, a physician should be consulted at once. Tobacco-smoking increases the amount of carbon monoxide in the blood and hence may to some extent contribute to the condition of anemia.

**The white corpuscles.* The white corpuscles are about one third larger, though far less numerous, than the red corpuscles. They are typical cells, with nuclei, and each is able to move about independently, like an amœba, through the walls of the capillaries and among the tissues (Fig. 205, p. 309). There are three kinds of white corpuscles, which engulf and digest bacteria and parts of injured tissue. These corpuscles also produce compounds which make growth and reproduction of cells possible. Pus is composed of the dead and living white corpuscles which have gathered at an infected point to attack invading bacteria. Where all the white corpuscles are formed is not clearly understood. Some, however, are formed in the red marrow; others, in the liver and the spleen of the child before it is born; and still others, in the lymph glands.

The blood plates. The third type of blood cells, the blood plates, cannot be seen in an ordinary sample of blood because they are so small and because they break up soon after the blood is taken from the body. They are smaller than red corpuscles, and are amœboid, like the white corpuscles. Their functions are not clearly known, but it is believed that they aid in the clotting of blood.

Blood clotting. We are all familiar with the fact that cuts and scratches usually stop bleeding after a few minutes. A certain protein (fibrinogen) in the plasma causes this clot. It forms long fibers which entangle the corpuscles. The clear yellowish liquid which is left after blood has clotted is *serum.* The use of blood serums in the treatment of several diseases will be discussed in a later chapter.

Sometimes in cases of great loss of blood from bleeding or in some cases of anemia and a few other diseases, lives are saved by performing blood transfusions. Blood from an artery of a normal person is transferred to the veins of the patient. Four types of blood are recognized. The transfusion can be successful only when the blood that is transferred corresponds closely to that of the patient.

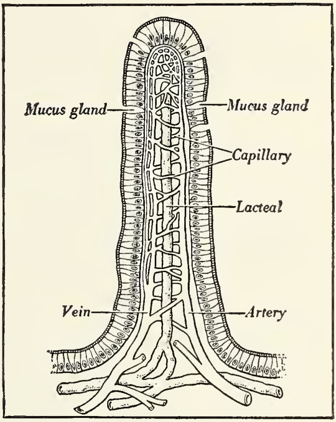


FIG. 217. Can you explain the functions of the various structures shown in this diagram of a villus?

How the food substances enter the blood. In the preceding chapter the absorption of the products of digestion by the villi of the small intestine was described. In the interior of every villus (Fig. 217) are lymph spaces surrounding a very complex network of blood capillaries. In the middle of this network is a lymphatic. The water, the minerals, and the nutrients pass into the tissue spaces around the capillaries and the lymphatic. These nutrients are (1) carbohydrates in the form of simple sugars, (2) digested proteins probably in the form of amino acids, and (3) digested fats (probably in the form of fatty acids and glycerol).

The minerals, the sugars, and the amino acids enter the blood capillaries, from which they pass into the portal vein (Fig. 213, p. 318). Unlike every other vein in the body, the portal vein ends not in a larger vein but in a network of capillaries. These capillaries form a complex network among the tissues of the liver. A small amount of the amino acids is needed to nourish the liver cells. Some of the amino acids are converted into sugar, and some pass into the blood stream. Most of the sugar passes through the liver capillaries into another vein (the hepatic vein) and thence to the heart. From 12 to 20 per cent of the sugar, however, is stored in the liver as a reserve supply (glycogen) of energy. This is

ready for immediate use by the body when the carbohydrate diet is insufficient or when there is need for unusual or violent activity.

The fats do not enter the blood stream directly. They pass into the lymphatics instead and are finally poured into the blood stream at the point where the lymphatic system joins the circulatory system in the neck (Fig. 213, p. 318).

***Assimilation and oxidation.**[1] Nobody yet knows exactly how the cells use the materials brought to them by circulation. Oxidation of food energy into heat energy, mechanical energy (or the energy of movement), and perhaps into other forms of energy is constantly taking place. The protoplasm of the cell is constantly undergoing chemical changes. As a result protoplasm is constantly being organized out of materials supplied from the blood stream. The process by which various materials brought to the cells by circulation are built into and made a part of protoplasm is known as *assimilation.* Assimilation may also be defined as the process by which living protoplasm organizes organic and inorganic matter into the new compounds which compose protoplasm.

***Summary of processes having to do with the use of food.** Assimilation and oxidation of food together constitute the sixth stage in the use of food energy by every living thing. The stages so far considered are (1) securing the food; (2) taking the food into the body (ingestion); (3) changing the food into liquids of such kinds that they can be taken into the blood (digestion); (4) taking the digested foods into the blood (absorption); (5) transporting the absorbed materials to every living cell in the body (circulation); (6) building new protoplasm (assimilation) and using food materials to supply energy (oxidation). Two more processes which are related to the use of food remain to be considered: (7) the process by which oxygen enters the cells and carbon dioxide and water leave it (respiration), and (8) the process of waste removal (excretion).

[1] To the Teacher. Some authorities include under respiration the release of energy by oxidation. The more general practice among human physiologists, however, seems to be to restrict the use of the term *respiration* chiefly to the exchange of oxygen and carbon dioxide, as discussed in the next chapter.

Self-test on Problem XV–D. **1.** Most of the blood consists of a *red* fluid called *lymph.*

2. Match each expression under B with one and only one of the words or expressions under A.

A	B
Lymph gland	Carries oxygen and carbon dioxide
Anemia	A disease which may be caused by carbon monoxide
White corpuscle	Destroys bacteria
Liver	Probably aids in blood-clotting
Red corpuscle	The liquid that remains after blood has clotted
Artery	First receives the digested food
Lymph spaces inside the villi	Where reserve sugar (glycogen) is stored
Blood plate	
Serum	
Portal vein	

3. Exercise has value in forcing *plasma* through the lymphatic system.

4. The process by which protoplasm is built and repaired is called __(?)__.

5. Name the eight processes concerned with the use of food.

Self-test on Biological Principles. **1.** Explain the meaning of this principle: "Protoplasm may be nourished only by food substances which have been reduced to liquid form by enzymes."

2. How many illustrations can you cite from this chapter to prove this biological principle: "Circulation is carried on in all living organisms"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Florists often have green carnations for sale on Saint Patrick's Day. These are really white carnations which have been dyed green. Can you explain how this dyeing might be done?

2. Can you give a reason to account for the fact that the circulatory system of the crayfish is more like that of the grasshopper than it is like that of the earthworm?

3. Which of the three types of circulatory system (p. 312) does the lymphatic system most closely resemble?

4. Does the blood nourish any cells directly? If so, which?

5. Why does the heart do less work when one is lying down than when one is sitting or standing?

6. What advantage is derived from the fact that the blood moves very slowly through the capillaries?

7. Why does the muscular wall of the left ventricle need to be stronger than that of the right ventricle? Why do the walls of the ventricles need to be thicker and stronger than those of the auricles?

8. How many points of contrast between the circulatory system and the lymphatic system can you state?

9. In what respects are the pulse and peristalsis alike and in what respects are they different?

10. What are some of the inorganic and some of the organic substances which are assimilated into protoplasm?

11. Explain how the valves in the veins keep the blood flowing in one direction.

12. How do parasitic flatworms secure digested food?

13. How does blood in the pulmonary veins differ from that in other veins of the body?

14. Why must the heart beat more rapidly when one exercises?

15. In Fig. 205, p. 309, can you find the white corpuscle escaping from the blood stream?

Exercise on Scientific Attitudes. In the fourth century B.C. Aristotle, the famous Greek philosopher, taught that the blood of man and the other higher animals was made in the liver from food, and that the blood was then sent to the heart and by it over the body through the veins. Until the time of Galen, in the second century A.D., it was believed that the arteries were merely "air pipes." Galen discovered that the arteries carry blood, but he thought they also carried "vital air," or "spirit." From that time until the time of Harvey, the English physician (1578–1657), only two great discoveries concerning the blood circulatory system had been made. These were the presence of valves in the veins and some facts about the circulation of blood between the heart and the lungs.

By careful work with many kinds of animals over a period of many years, Harvey established the facts of the circulation of the blood and of the functions of the heart and the blood vessels. Harvey's discoveries are all the more remarkable because he had no microscope but only a simple lens.

Malpighi, an Italian physiologist, in 1661 observed the flow of blood between veins and arteries through capillaries. He thus proved that veins and arteries are parts of the same system, as Harvey had stated earlier that they must be. Leeuwenhoek a few years later confirmed Malpighi's discovery by observations through his microscope of the circulation through the capillaries of a bat's wing and of a tadpole's and a fish's tail.

Which of the scientific attitudes (pp. 12 and 13) are illustrated by these facts concerning the history of the study of the circulation of blood?

Class Project 19. To find out whether mental conditions such as excitement, worry, fear, and the like affect the rate of pulse beat. Practice until you can take your own pulse accurately. At various times take your pulse — for example, just before you take a test or examination, just before a party or a school game, and so on. Try to find out whether excitement, fear, worry, happiness, and the like have any effect upon your pulse. Combine the results of a week's observations by the entire class and see whether the results indicate definite conclusions.

Exercise on Scientific Method (Evaluating Procedures). What was the advantage of making this a class project rather than an individual one? Could you be sure that all the class members who collected facts or data had the same idea concerning what was a state of fear, excitement, worry, and the like?

Special Reports. 1. Consult a physician to find out what are some dangerous conditions which high blood pressure may indicate.

2. What are "bleeders" (the medical term for one type is hemophilic)?

Chapter XVI · The Process of Securing Oxygen and Eliminating Carbon Dioxide (Respiration)

Questions this Chapter Answers

Why is respiration necessary?
How is respiration in plants like photosynthesis, and how is it different?
What are the important characteristics of respiration in typical animals?
Why is the respiratory system of higher animals inclosed?
What are the structures and the functions of the human respiratory system?
How are these structures used in breathing?

Problem XVI–A · How is Respiration Carried On in Plants?

The necessity for respiration. Every living organism must secure a constant supply of oxygen and must get rid of carbon dioxide in order to live (Fig. 218). Without the oxygen to combine with the food in the cells, food energy could not be transformed into heat energy, mechanical energy, and other forms which the organism needs. Moreover, unless the carbon dioxide which results from the oxidation of food in each cell is removed, the life processes in the cell stop, just as a fire is extinguished if the carbon dioxide is not allowed to escape. Thus if amœbas are placed in water which contains no oxygen in solution, the animals will contract into spheres and will form thin-walled cysts. They will remain perfectly quiet. If no oxygen is admitted to the water, the amœbas will finally die. The same results follow if amœbas are placed in water which is strongly charged with carbon dioxide.

***The nature of respiration.** The process of respiration is concerned fundamentally with the passage of oxygen into the cell and the passage of carbon dioxide and water out of the cell. In the higher animals this transfer is made directly between the cells and the blood (internal respiration) and between the blood and the lungs or the gills (external respiration). In the higher animals, therefore, respiration is made possible by breathing.

But none of the plants and none of the lower animals breathe. Respiration, however, goes on in every living cell, whether plant

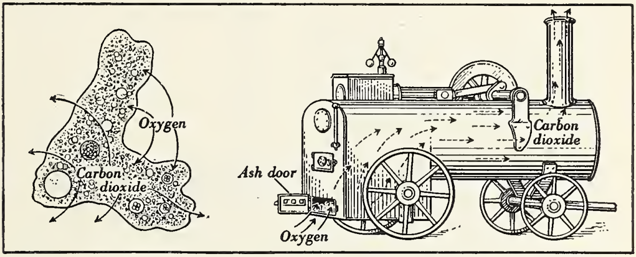


FIG. 218. In what respects is the amœba like the engine?

or animal. Though the functions of respiration are the same in all living things, the means by which organisms carry on respiration vary considerably, as will be seen from a study of typical plants and animals.

Respiration in plants. In the simplest plants respiration is usually carried on by means of osmosis. Some of the bacteria are able to use the free oxygen which is dissolved in the water, blood, milk, or whatever other fluid their habitat may be. Others (the anaërobic bacteria) cannot use free oxygen; in fact, free oxygen kills them. These must secure their necessary oxygen from compounds which they take in along with their food or as a part of it. All bacteria get rid of carbon dioxide through their walls by osmosis.

No plants simpler than the mosses are known to have any definite structures which aid respiration. Some but not all of the mosses have crude stomata through which gases enter and leave the plant.

Experiment 72. **1.** Does a green plant, such as a bean plant, give off carbon dioxide as a product of respiration? Put into each of two large wide-mouthed jars, such as fruit jars or battery jars, a two-inch layer of rich, damp, sandy soil. Plant in the soil of one jar two or three bean seeds which have soaked overnight. Keep the jars in a warm sunny place for several days until the bean plants have developed their second leaves. Now put into each jar a small dish of limewater. Put a cover over each jar to exclude the air and place both jars side

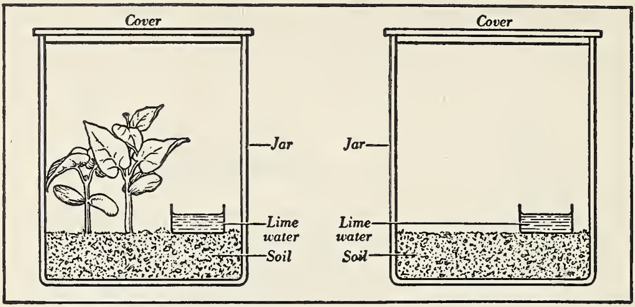


Fig. 219. **Exercise on Scientific Method (Evaluating Procedures and Inventing Check Experiments) :** Does this experiment help to prove whether or not respiration takes place in *all* green plants? Describe one or more other experiments which would help to answer the question at the beginning of Experiment 72

by side in a window (Fig. 219). From time to time observe the limewater in both jars. Answer with a complete statement the question asked at the beginning of this experiment.

2. Will seeds grow without a supply of oxygen? Secure two small fruit jars or bottles with stoppers. Into each put some moist sawdust or wet paper. Put six soaked bean seeds or other seeds into each jar. Close one jar tightly so that no air can enter. Leave the other jar open. Examine daily for a week. In which jar do the seeds grow better?

Exercise on scientific method.* 1. *Using controls and isolating the experimental factor. In the first part of this experiment what was the control? What conditions or factors were identical in both jars? What condition was different? This was the experimental factor.

2. *Making inferences and planning check experiments.* In the second part of this experiment did any of the seeds in the sealed jar grow? How do you explain this? (Remember that there was air in the jar when you sealed it.) Can you plan a check experiment similar to the last one, except that all the oxygen is removed from the sealed jar?

In the higher green plants there are stomata in the leaves and young stems and lenticels in the stems and twigs, which together provide for respiration. The passage of gases into and out of the stomata of the leaves has already been discussed in connection with photosynthesis. The lenticels develop from stomata in this way: The stems of young plants have stomata, fewer in number than those in the leaves but like them. As the tree gets older,

the growth of stem tissues tends to close these openings. Just beneath the stomata, however, a tissue of large thin-walled cells is formed with spaces between the cells. As the tissue grows it breaks through the outer covering (epidermis) of the trunk, offering a ready means for gases to pass inward and outward (Fig. 220, *A*). Lenticels may easily be seen on twigs of the plum, the birch (Fig. 220, *B*), or the cherry.

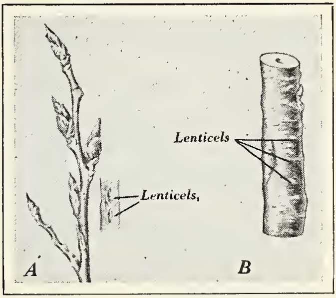


FIG. 220. *A*, lenticels on a twig; *B*, lenticels on birch bark. Why are lenticels more necessary on a young stem or twig than on an old one?

***Respiration and photosynthesis compared.** Respiration in plants is sometimes confused with photosynthesis. The two processes are, however, very different. The confusion arises from the fact that in photosynthesis green plants use carbon dioxide from the air and give off quantities of oxygen as a by-product. This statement does not mean, however, that green plants do not use oxygen. Every living cell in green plants, as in every other organism, uses oxygen in changing its food energy into other forms of energy. In respiration the plant gives off some carbon dioxide and water as waste products.

Self-test on Problem XVI–A. 1. *Oxygen* is as necessary to life as food and water.

2. *Some* animals would die if they were unable to get rid of *carbon dioxide* gas.

3. Respiration in all animals takes place in the *lungs*.

4. Respiration in the simplest plants is carried on by the process of *transpiration*.

5. Gases pass into and out of higher plants through __(?)__ and __(?)__.

6. *Oxygen* is a by-product of photosynthesis.

7. The process of respiration takes place in *most* organisms, but the process of breathing takes place in the *lower* animals.

Problem XVI–B · How is Respiration Carried On by those Animals which Obtain Oxygen Dissolved in Water?

Respiration of animals living in the water. As in the simplest plants, respiration in Protozoa is effected by osmosis of oxygen from the surrounding liquid and of carbon dioxide into the surrounding liquid. And with simple animals of many cells, like the sponge, oxygen and carbon dioxide are exchanged directly by the cells of the body walls (Fig. 221).

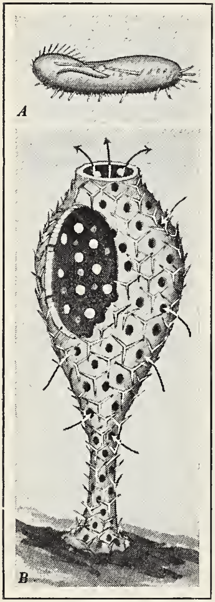


FIG. 221. Neither the protozoan *A* (*Stylonychia*) nor the sponge *B* (*Olynthus*) needs gills or special breathing apparatus. Explain

The starfish has special structures, though simple ones, for respiration. Scattered over the spiny surface are tiny pores, almost too small to be seen with the naked eye. Delicate tissue is thrust out through these pores into the water, providing a considerable surface area through which oxygen passes from the sea water into the body fluid and carbon dioxide passes out at the same time into the water.

The mussel, clam, and oyster have not only gills but also special structures which maintain a constant flow of water over the gills, just as man's breathing apparatus brings fresh supplies of air to the surface of the lungs. Gills consist of delicate, thin-walled membranes arranged like the teeth of a comb, so that there is an enormous surface. A network of blood capillaries just under the surface of the gills makes possible a ready exchange of carbon dioxide from the blood into the water and of oxygen from the water into the blood.

The crayfish is well provided with gills. These are not inside the body cavity but are between the body wall and the gill cover. Each gill with its stem and many branching filaments[1] looks like

[1] *Filament* (fil'a ment): a fine thread or something which is like a thread.

a plume (Fig. 222). In the front end of the gill chamber is an organ called the *bailer*. This bailer moves back and forth, forcing water out through an opening in the front and thus forming a partial vacuum in the gill chamber. The greater pressure of the water outside forces fresh water into the gill chamber through a rear opening, thus providing a continuous circulation. Blood flowing through the gill stems and the filaments gives off carbon dioxide and takes in oxygen.

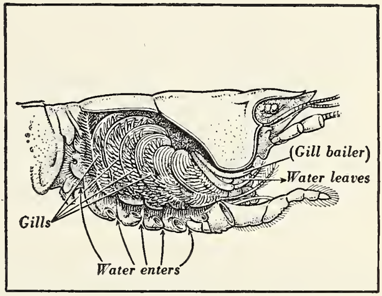


FIG. 222. What is the advantage of the plume-like structure of crayfish gills?

Along the sides of the head of a fish are two flaps, the gill covers (opercula; singular, operculum), which open and close regularly. The fish takes in a mouthful of water, then closes its mouth and forces the water back over the gills and out past the gill covers.

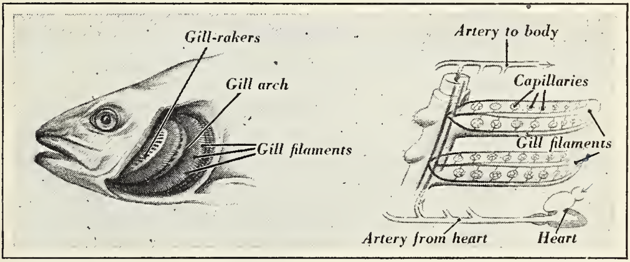


FIG. 223. A fish that eats crayfish, mollusks, or other fish has very short gill-rakers, but a fish that feeds on minute plants and animals has numerous long gill-rakers. Explain. What in this picture corresponds to the pulmonary artery in man?

Under each gill cover there are four or five gills. A gill is composed of a bony arch to which are attached many short fleshy filaments (Fig. 223). These filaments have very thin walls, so that carbon dioxide and oxygen pass through readily. Moreover,

the great number of them increases the surface which can absorb oxygen. Inside each filament there are numerous capillaries which bring the blood into close contact with the water. As the blood circulates through the filament, carbon dioxide is given off and oxygen is taken into the blood stream. The fish has nostrils, but these serve only as organs of smell.

On the inner edge of the gill arch are bony projections called gill-rakers. They serve the double purpose of straining out bits of food that the fish can use and of catching solid pieces which, if allowed to pass from the mouth to the gills, might tear the delicate gill filaments.

Self-test on Problem XVI–B. 1. In order to survive, Protozoa must have a supply of oxygen constantly *leaving* the cells and carbon dioxide constantly *entering* them.

2. Match each word under B with one and only one word or expression under A.

A	B
Lenticel	Man
Gills	Protozoan
Carbon dioxide a life necessity	Starfish
Photosynthesis	Mollusk
Lungs	Crayfish
Neither lungs nor gills but tissue to absorb oxygen	Fish
	Mammal
Transpiration	
Secures oxygen only by osmosis	
Vascular bundle	
Stoma	
Oxygen a by-product	

Problem XVI–C · How is Respiration Carried On by Animals which Get Oxygen directly from the Air?

Respiration of air-breathing animals. Although the earthworm has a complex circulatory system, nevertheless its manner of respiration is simple. It takes oxygen into its body and gets rid of carbon dioxide through all portions of its moist skin. Just beneath the skin are numerous thin-walled capillaries. Through the walls of these oxygen and carbon dioxide readily pass. The

exchange of gases through the moist skin and moist membranes is probably caused by osmosis. Oxygen combines with the red

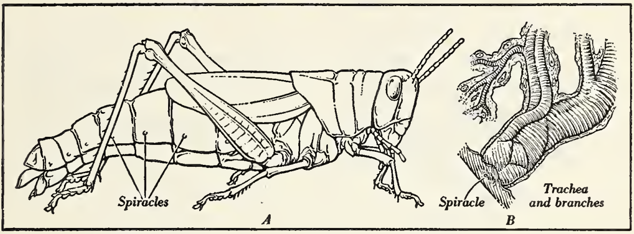


FIG. 224. The breathing pores and air tubes of a grasshopper. Compare the means of respiration of the snail with that of the earthworm and the grasshopper. Do the respiratory structures of these animals furnish an example of, or an exception to, the biological principle "In general, the more complex the organism, the more complex its various structures." Justify your answer

corpuscles of the blood, as in the higher animals, and is circulated to every cell. Carbon dioxide, mostly in solution in the blood, is carried from all parts of the body to the capillaries under the skin.

In the grasshopper no use is made of the vascular system in carrying oxygen to any of the cells or carbon dioxide from them. Moreover, if one were to trace the mouth cavity back into the body, one would search in vain for any structures having to do with respiration, because the grasshopper does not breathe through its mouth. How, then, is the grasshopper supplied with oxygen, and how does it get rid of carbon dioxide?

In Experiment 45 (p. 195) you found along each side of the abdomen of the grasshopper eight small holes, and two more along each side of the thorax. These are the breathing pores (spiracles), which are the beginnings of a complex system of air tubes (Fig. 224). The mouth of each breathing pore is kept open by a ring of the same material (chitin) as that which composes the skeleton of the insect. A valve at the tube mouth helps to prevent the entrance of dust. The tubes (tracheæ), leading from the breathing pores, branch again and again, and thus lead to every part of the insect's body. Carbon dioxide passes directly from the cells through the tube walls into the tubes, while oxygen passes from the tubes into the cells in the same way. The grasshopper breathes by expanding

the abdomen, forming a partial vacuum in the air tubes. The air pressure outside then forces air into the tubes. When the abdomen

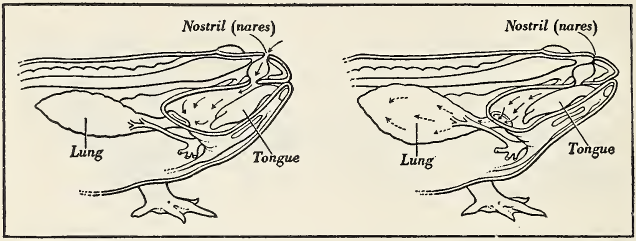


Fig. 225. Why does a frog keep its mouth closed while breathing, although a fish does not? Can you explain from this diagram what takes place when a frog inhales and exhales?

is contracted, the air in the tubes is compressed, and some of it is therefore forced out of the tubes.

The snail, although lower in the scale of life than the grasshopper, has a more complex respiratory system. It has a primitive lung. In some forms this primitive lung branches into a number of smaller air tubes (tracheæ). The membrane (mantle) lining the lung cavity is richly supplied with blood vessels, which take up oxygen and get rid of carbon dioxide, as in the higher animals.

To some extent the frog eliminates carbon dioxide and takes in oxygen through its moist skin both when the animal is in the water and when it is on land. The exchange of carbon dioxide and oxygen is accomplished chiefly, however, through the moist membranes of its lungs. In the back of the mouth is a slit (glottis) leading into a short tube (trachea) which branches to the lungs. These are two elastic sacs, the inner surfaces of which are greatly increased by numerous folds in the walls, forming small spaces (alveoli). The thin walls contain a network of blood capillaries.

When the frog breathes, it keeps its mouth closed. When it inhales, or breathes in, it lowers the floor of its mouth, forming a partial vacuum in the mouth cavity and opening the nostrils (Fig. 225). The greater air pressure outside forces air through the nostrils into the mouth cavity. The floor of the mouth is then raised, closing the nostrils and compressing the air in the mouth

cavity. The compressed air is forced into the lungs. When it exhales, or breathes out, the frog contracts the muscles in the body wall, compressing the air in the lungs and forcing it into the mouth cavity. If you watch the underside of the mouth, you can see the breathing movements.

The ability of the frog to "breathe through its skin" enables it to hibernate.[1] As cold weather approaches, the frog goes to the bottom of a pond or stream and burrows into the mud. Here it remains all winter. If dug out, it is apparently dead. This dormant state is due to the fact that all the life processes are very nearly at a standstill. While hibernating, the frog can get only such oxygen as can be taken in through the skin. Also oxidation of food goes on only fast enough to keep the animal barely alive. All cold-blooded animals have this ability to live when their temperature is reduced to that of their surroundings. When warm spring weather comes, the frog again becomes active.

The respiratory systems of higher animals must be inclosed. The frog is able to use its skin as an organ of respiration because it can keep its skin moist by immersing itself frequently in the water. If it were long away from the water, it would be unable to replace from its body fluids all the moisture evaporated from its skin. Hence it would die. Higher animals, living on land, cannot exchange carbon dioxide and oxygen through their skins because they are not so constructed as to be able to supply to their skins the great amounts of water which would be evaporated in the process. They are able to survive only because they have their breathing surfaces inclosed within their bodies, where evaporation will not be great. There is little evaporation from the lungs and nasal passages of higher animals for the same reason that there is little evaporation from the contents of a bottle which has a small neck.

***Summary.** Respiration in every organism takes place only through moist cell walls. The simplest plants, such as bacteria, and the simpler water animals secure oxygen and get rid of carbon dioxide directly through the cell walls by osmosis. The higher green plants have special structures, stomata and lenticels, through which these gases pass to and from the interior of leaves

[1] *Hibernate* (hi'ber nate): to pass the winter in inactive condition in burrows or dens. *Hibernation* (hi ber na'shun): act or state of hibernating.

and stems. In the more complex animals special respiratory structures are necessary in order to provide enough oxygen to the cells farthest from the surface and to remove carbon dioxide as fast as it is returned from them. The starfish, a fairly complex animal, has special tissues over all its body which function in this way. Still more complex animals cannot be served by simple structures scattered in various parts of the body. These have specialized structures of respiration located in one part of the body. As with the structures concerned with digestion, circulation, and other physiological[1] processes, in general the more complex the animal, the more complex its respiratory system needs to be. There are, however, some interesting exceptions to this biological principle. For example, the earthworm, an annelid, has a simpler means of respiration than the starfish, an echinoderm. The simplest animals have their respiratory structures exposed; the highest animals have their respiratory structures inclosed to prevent excessive evaporation.

*All the land animals above the frog in the scale of life, namely, the reptiles, the birds, and the mammals, eliminate carbon dioxide and secure oxygen by means of lungs. There are minor differences in the breathing structures of the different higher animals, but no differences so great as those that have been described in the preceding paragraphs. The remainder of the chapter will therefore be devoted to the breathing structures of man as a representative of the higher chordates.

Self-test on Problem XVI–C. **1.** The earthworm takes in oxygen and gets rid of carbon dioxide through its *mouth.*

2. In the *insects* air tubes serve the same purposes in making possible the transfer of oxygen to the blood and carbon dioxide from it that are served by __(?)__ in the higher animals.

3. The simplest animal here discussed which has true lungs is a (1) mollusk; (2) arthropod; (3) mammal; (4) protozoan; (5) annelid; (6) angiosperm; (7) cœlenterate.

4. The *Amphibia* are able to breathe partly through their skins because they live *always* in the water or in damp places.

5. All vertebrates except the __(?)__ breathe partly or wholly with lungs.

[1] *Physiological* (fiz i o loj′i kal): having to do with functions of structures concerned with life processes.

Problem XVI–D · How is Respiration Carried On by Man?

* **Structure and functions of the human respiratory system.** The respiratory system in man is a continuous tube with an enormous number of branches at the lower end. The conspicuous divisions of this system are the nose, the pharynx, the larynx, the trachea, or windpipe, the bronchi, and the lungs. The latter consist of the bronchial tubes and the innumerable small sacs (alveoli) in which they end (Fig. 226). The tube is open throughout except at the larynx, or voice box, which opens through a valve-like slit into the pharynx, or throat cavity. One can gain an understanding of the respiratory system of man by examining that of a chicken.

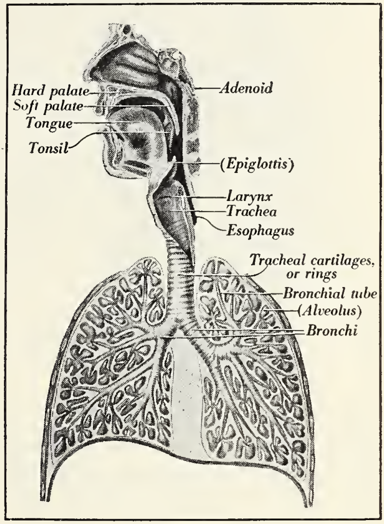


FIG. 226. Can you locate on this diagram the conspicuous divisions of the respiratory system? What other structures are labeled? The inner surfaces of the lungs have a total area over one hundred times that of the body

In man the passages of the nose are lined with mucous membrane. Beneath this membrane is a complex network of blood capillaries. The mucous membrane serves to moisten the incoming air, and the blood capillaries supply sufficient heat to raise its temperature almost to that of the body. The nostrils are equipped with coarse hairs which act as a strainer, or filter, freeing the air from dust particles.

The windpipe is a tube about five inches long by about an inch in diameter. It has sections of cartilage in its walls to prevent its closing. The two bronchi and the larger bronchial tubes likewise have these sections of cartilage, but the smallest bronchial

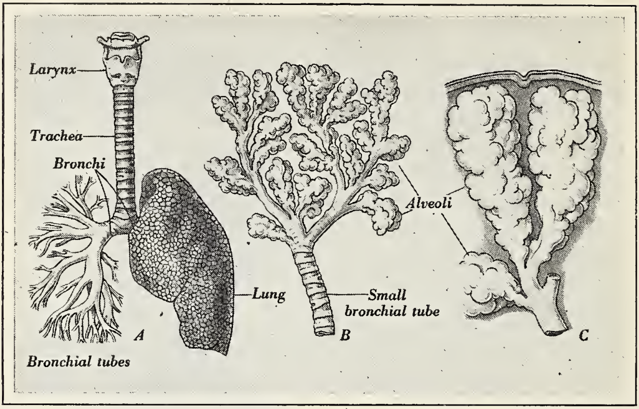


FIG. 227. Lung structures: *A*, lungs and air passages; *B*, enlarged drawing of small bronchial tube; *C*, enlarged drawing of one of the final branches. Why is it necessary to have a many-branched lung rather than a solid mass of lung tissue?

tubes are not so equipped (Fig. 227). Each cell of the lining of the windpipe, the bronchi, and the lungs is equipped with hairlike cilia. These are constantly in motion. If a section of the lining is examined through a microscope, it looks like a field of grain when breezes pass over it. Since the cilia all move with more force in the direction of the throat than toward the lungs, the motion tends to carry dust, smoke particles, and other solid particles upward into the throat. It is said that a coal-mine worker, in whose lungs a great amount of coal dust collects, will become free of the dust by this action of the cilia if he leaves the dust-laden air, even though several months may be required.

We may think of the lungs inclosed in their sacs (the pleuræ) as being in a box (the thorax) of which the top is formed by muscles and tubes, including the esophagus and various blood vessels. The sides are formed by the backbone, the breastbone, and the ribs, with the attached muscles. The bottom is formed by the diaphragm, which is a dome-shaped sheet of tissue separating the chest cavity from the abdominal cavity (Fig. 228).

The lungs are two baglike structures lying one on each side of

the chest, with the heart between. Each lung is inclosed in an elastic air-tight sac (pleura). The walls of this sac are moistened with fluid, which lessens the friction caused by the lung movements. It is estimated that each lung contains about four hundred million tiny air sacs. Through the thin walls of these sacs oxygen passes into the blood capillaries and carbon dioxide and water vapor pass from the capillaries into the sacs. It is estimated that the entire absorbing space of the lungs equals an area about fifty feet square.

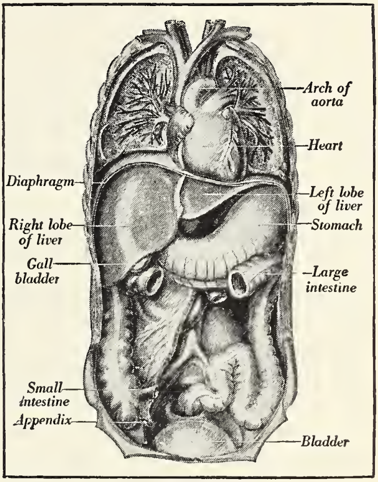


FIG. 228. The diaphragm and other respiratory structures. In what respects are the human lungs and a fish's or a crayfish's gills similar?

How we breathe. Inhaling is accomplished as the result of these separate movements: (1) The muscles of the diaphragm contract, pulling the diaphragm downward and thus forcing the organs of the abdomen downward and causing the walls of the abdomen to bulge outward. (2) Certain muscles attached to the ribs and breastbone contract, pulling the ribs and the breastbone upward and otherwise enlarging the lung cavity. Each of these movements enlarges the chest cavity, producing a partial vacuum between the lungs and the walls of the lung cavity, causing the lungs almost to fill the cavity around them. The greater air pressure outside the body, therefore, forces air through the nose and windpipe into the lungs until the air pressure inside and outside the lungs is the same.

When one is exhaling, air is forced out of the lungs in this way: The diaphragm arches upward. The muscles of the abdominal wall and others produce a pressure inside the abdomen, forcing

the diaphragm up farther. The bones of the chest immediately sink downward. The lungs are therefore compressed, and the air pressure in them is increased. Some of the air is therefore forced out of the lungs until the air pressure is again the same inside as out.

A grown person normally has on an average about eighteen inspirations[1] per minute. Children have more. Babies less than a year old have more than forty inspirations per minute. The number of inspirations may decrease nearly one third during sleep. The inspirations during sleep, however, are deeper than when one is awake.

Self-test on Problem XVI–D. 1. Trace air from the time it enters the nose until it is breathed out of the nose.

2. The air which enters the respiratory system is made both *dry* and *warm.*

3. Hairs in the nose remove __(?)__ from the incoming air.

4. The lungs have enormous surface areas in order to provide ample surfaces for absorbing __(?)__ and getting rid of __(?)__.

5. When the air pressure outside the lung cavity is greater than that within the lung cavity, air is *pulled* into the lung cavity.

6. Oxygen enters and carbon dioxide leaves the blood stream through the walls of the lungs at the *same time.*

Self-test on Biological Principles. What evidence is there in this chapter that complexity of structure goes hand in hand with division of labor?

Self-test on Organization of Facts. In what respects is the respiratory apparatus of each animal discussed in this chapter more complex than that of the animal preceding it?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Why will a frog or a toad die if its skin becomes dry? Why must all Amphibia live usually in water or in damp places?

2. What advantage is derived from the fact that the smallest bronchial tubes are not equipped with sections of cartilage?

3. After a heavy rain one may find many earthworms on the surface of the ground. If they remained in their burrows, they would drown. Explain.

[1] *Inspiration* (in spi ra'shun): act of inhaling, or drawing in the breath.

4. Why cannot one drown a grasshopper by holding its head under water?

5. How does the exchange of oxygen and carbon dioxide in an amœba resemble respiration in man? How does it differ?

Exercise on Scientific Method. 1. Making Inferences. When a crayfish is resting in running water, it stands with its head pointed in the direction the stream is flowing. A fish, on the other hand, rests with its head pointed against the current. Can you use your knowledge of the methods of breathing of these two animals to explain the probable reason for this difference?

2. Inventing Experiments. Can you plan an experiment which will show whether or not germinating seeds give off carbon dioxide? Be sure to introduce controls.

Special Report. Find out all you can about the respiration of the larvæ of certain insects which in the larval stage are water animals but later live on land, such as the dragon fly, the May fly, the mosquito. (Consult a textbook of entomology or an advanced textbook of zoology.)

Chapter XVII · Getting Rid of Waste Products (Excretion)

Questions this Chapter Answers

What is the meaning of excretion?
How is excretion carried on in plants and animals?
What are the organs of excretion in man, and how does each function?
Of what importance is excretion?

Problem XVII–A · What is the Nature of Excretion?

The meaning of excretion. If an automobile engine or a coal furnace were constructed without some means by which waste products of combustion could escape, it would not function. The transformation of energy in the automobile engine or in the coal furnace can continue only if the waste products are removed about as rapidly as they are produced.

In earlier chapters of this book it was stated that energy is constantly being transformed in every living cell. Waste products are constantly being formed as a result of metabolism in the cell (Fig. 229). Like the automobile engine and the furnace, the cell will cease to function, and consequently the organism will soon die, if its waste products cannot be eliminated.

*Waste products of living things may be placed in three groups: (1) the solid portions of food which are not digested or which cannot be digested; (2) the excess water which is not used by the body; (3) the waste products which result from metabolism in the cells, namely, carbon dioxide, urea, other organic compounds, and water. The various processes by which an organism gets rid of its wastes are called *excretion*.[1]

[1] To the Teacher. It is recognized that technically excretion includes the elimination only of the products of metabolism, namely, carbon dioxide, urea, other organic compounds, and water. For the sake of simplicity, however, the term *excretion* is here used to include the elimination of all wastes. This chapter discusses chiefly excretion of wastes from metabolism, since the elimination of other wastes is discussed in preceding chapters.

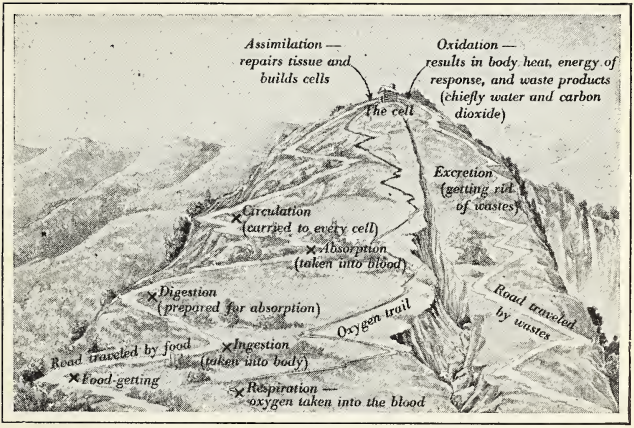


FIG. 229. The metabolism trail. Can you explain this diagram? What processes occur before metabolism takes place? What processes are included in metabolism?

The chapter on digestion discussed the elimination of undigested food materials from the intestines. In the simpler animals undigested solid wastes are cast out through the cell walls or through the mouth. In most of the animals which have a digestive system solid wastes are eliminated from the intestines. Solid wastes of plants are deposited in the leaves, in the stones of certain fruits, and in the pith cells. The shedding of leaves is one means by which plants get rid of these wastes.

The chapter on respiration described the elimination of carbon dioxide as taking place at the same time and by means of the same structures as the securing of oxygen. Carbon dioxide passes out through the cell walls in the simplest animals and plants, probably by osmosis; through the stomata and lenticels of higher plants; through the breathing pores of insects; and through the gills and lungs of more complex animals.

This chapter will deal in general with the whole subject of elimination of wastes, but it will discuss chiefly the excretion of water, of nitrogenous[1] wastes, and of other products of metabolism.

[1] *Nitrogenous* (ni troj'e nus): composed partly of nitrogen.

Self-test on Problem XVII–A. **1.** Waste products are formed whenever food is oxidized.

2. Excretion is made necessary by *metabolism.*

3. The chief waste products resulting from metabolism are __(?)__, __(?)__, and __(?)__.

4. Carbon dioxide leaves the body through the __(?)__; solid wastes are eliminated from the __(?)__; other waste products are dissolved in *water* which is eliminated.

5. In higher plants solid wastes are eliminated by the shedding of the *leaves.*

Problem XVII–B · How is Excretion Carried On in Plants and Typical Animals?

Excretion in plants. Since urea[1] and the other waste products of cell activities are soluble in water, they are largely eliminated along with the excess water. In the lower plants, therefore, excretion of such products is effected through the cell walls. In the higher plants organic wastes enter the sap from each cell and are carried through the vascular system to other parts, particularly to the roots, where they can be eliminated. If the organic wastes which are eliminated from the roots are not later carried away from the roots by the soil water, the plant dies. It will be seen that in higher plants and, as we shall see later, in higher animals the vascular system is as necessary in removing waste products from all the living cells as it is in bringing them food, oxygen, and other necessary materials.

Excretion in typical animals. Having no digestive system *Amœba* gets rid of undigested materials by simply moving away and leaving them behind. It eliminates excess water and with it urea and perhaps other organic compounds in solution, thus: In the single-celled body of an amœba (Fig. 230) is a bubblelike cavity (contractile vacuole). At fairly regular intervals this cavity fills with water from within the cell, growing in size as it does so. Then it contracts, discharging outside the water with its dissolved waste compounds.

[1] *Urea* (u re′a): a waste product of metabolism resulting from the oxidation of proteins.

Paramecium has two of these spaces, or special cavities (contractile vacuoles), one at each end of the body, for eliminating

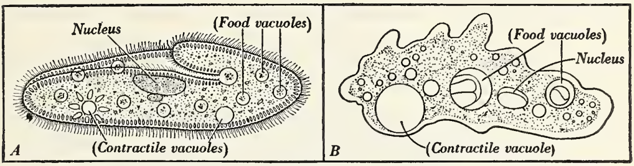


FIG. 230. Can you explain these diagrams showing excretion in *Paramecium* and *Amœba*?

water and dissolved cell wastes (Fig. 230). Each is connected with a number of smaller cavities which extend from it like the spokes of a wheel. Water enters these small cavities from the protoplasm. When they are full, they contract, discharging their contents into the larger cavity. When this in turn is full, it discharges outside. The food follows the path indicated by arrows (Fig. 165, p. 252) and is digested as it moves along. Solid particles which remain are discharged through a definite point in the cell wall.

The earthworm, as well as a few animals lower in the scale of life, has simple organs of excretion. These consist of a pair of slender coiled tubes (nephridia) in every segment of the animal, except the first three and the last (Fig. 231). These tubes extract urea and other wastes from the blood.

The grasshopper, like all other insects, has small tubes (Malpighian tubes) of considerable length. These run throughout the body, collecting from the blood urea and other products of excretion and emptying them into the digestive tube through openings at the beginning of the small intestine. Some recent investigations seem to indicate that the molting of insects serves as a means of excretion. In these experiments insects that had been starved continued to molt, though their bodies no longer filled their exoskeletons.

The mussel or clam has an organ of excretion on each side of the body. Each of these organs consists of a U-shaped tube. One end of the tube is a simple kidney; the other end is a thin-walled urinary bladder. Both the wastes stored in the bladder and those from the intestine are carried out of the body through the siphon.

In the fish waste products other than carbon dioxide resulting from the activities of the cells pass into the blood, which carries

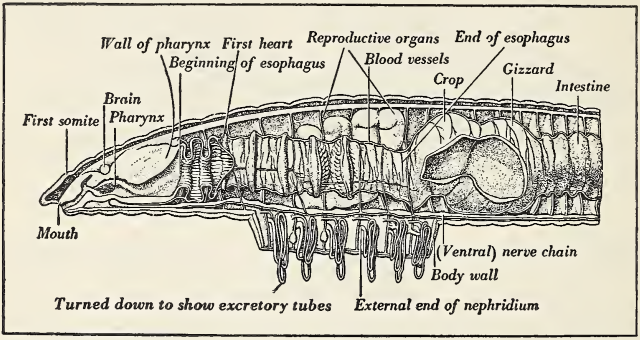


FIG. 231. The internal structures of the earthworm. How does the means of excretion in the earthworm mark an advance over those in animals lower in the scale of life, for example the protozoans and the sponges?[1]

them to the two kidneys. These lie just under the backbone in the body cavity. The kidneys extract urea and other organic wastes. These wastes are carried by thin tubes (ureters) into a urinary bladder. The tube from the bladder leads out of the body at a point just back of the opening (anus) from the intestine (Fig. 134, p. 211).

In all the higher animals both the liver and the skin are organs of excretion, as will be explained.

*__Summary of general facts about excretion in plants and animals.__ Excess water, which always contains in solution waste products resulting from cell activities, is eliminated from the simpler organisms chiefly by osmosis through the cell walls. In the higher animals these waste products after elimination from the cells are carried through the vascular system by the blood to special organs, which separate them from the blood and get rid of them. These special organs make up the excretory system. The excretory system in its simplest form is merely a system of tubes running through the tissues of the body and emptying

[1] From Meier and Meier's *Essentials of Biology.*

either outside the body or into the digestive system. In higher animals these tubes are not located in various parts of the animals, but are grouped together in one organ, the kidney, because the blood brings the wastes to the kidney.

In the higher animals the urine from the kidney is stored in a bladder. In the most complex animals part of the excess water containing cell wastes is eliminated through the skin. The liver is an organ of excretion, as well as an organ of digestion and food storage. It eliminates wastes into both the blood and the small intestine. Thus in these animals the excretory system consists of the kidney and bladder with the tubes leading from them, of the liver, and of the skin.

Self-test on Problem XVII–B. 1. When higher plants shed their leaves, they get rid of some __(?)__ wastes.

2. The Protozoa have *rudimentary* organs of excretion.

3. The earthworm has *one pair* of excretory organs.

4. Some scientists believe that insects excrete some of their organic wastes by the action of simple excretory organs and the rest by means of shedding their __(?)__.

5. A simple kidney and a urinary bladder are found as low in the scale of life as the __(?)__.

6. In the higher animals the *bladder* extracts wastes from the blood; these wastes are stored in the *kidneys* until they can be eliminated.

7. In the higher animals the __(?)__, as well as the kidneys, serves as an excretory organ.

Self-test on Organization of Facts. In this problem the advance toward a more complex excretory system in the animals described were these:

No organs, but definite points in the single-celled body where the solid and liquid wastes are eliminated.

Osmosis: forcing out liquid wastes through any portion of a cell wall; moving away and leaving the wastes behind.

More highly specialized organs of excretion: kidneys. bladder, and liver.

Division of labor: simple organs of excretion; many pairs of slender coiled tubes for collecting excess water and urea.

Instead of many pairs of tubes, one pair of complex tubes.

Can you arrange these in order of increasing complexity and name the animal or animals which illustrate each of these advances? Can you name the phylum to which each animal belongs?

Problem XVII–C · How is Excretion Carried On in Man?

Changing nitrogenous wastes. In an earlier chapter we learned that the energy foods were carbohydrates, fats, and proteins, and that unlike the fats and carbohydrates the proteins "serve not only as fuel but also as material for building and replacing protoplasm." If more protein is eaten than is needed for growth and replacement of protoplasm, the rest is used as fuel. The nitrogen portion of the digested proteins (amino acids), however, cannot be burned in the cells. Hence a chemical change takes place in which the nitrogen portion is thrown out as waste, and the remainder is burned in the cells as fuel.

These nitrogenous wastes are in the form of ammonium compounds and are poisonous in the blood unless they are in extremely small quantities. They must therefore be changed immediately into urea, which is harmless in the blood if it does not become too highly concentrated. All living cells can change amino acids into fuel by separating the nitrogen portion from the rest. Moreover, all can change the poisonous ammonium compounds into urea. Making this necessary chemical change is an important function of the liver.

The liver an organ of excretion. Ammonium compounds which have not been changed to urea in the cells are carried in the blood to the liver. Here they are changed into urea and thus made harmless. The urea produced by the cells and by the liver passes into the blood, which carries it to the kidneys. The kidneys separate the urea from the blood and eliminate it.

The liver performs important excretory functions other than that of changing nitrogen compounds to urea. In Chapter XV we learned that the liver breaks up worn-out red corpuscles and excretes the waste material as part of the bile. It also takes out of the blood certain waste products resulting from metabolism within the cells.

The urinary organs.** ***Experiment 73. What are the characteristics of a kidney? Examine a pig's, a calf's, or a sheep's kidney. Can you find where the blood vessels enter and leave the kidney? Can you find the tube (ureter) through which the urine passes from the kidney? Cut the kidney in half lengthwise. Describe the structure in a brief paragraph. Use sketches to help make your meaning clear.

The urinary organs consist of the kidneys, the bladder, and the tubes leading from the kidneys to the bladder and from the bladder outside the body (Fig. 232). The kidneys are two bean-shaped organs about four or five inches long, located one on each side of the body near the small of the back. They are composed largely of blood vessels and of small tubes which are very close to the blood vessels. The kidneys purify the blood by removing from it urea and other substances, including excess water, which are not needed by the blood. How the kidneys perform this function is not yet known. The product of the action of the kidneys is urine. Urine is made up of about 96 per cent water and 4 per cent dissolved solids. In each kidney it passes from the small tubes into larger ones and finally into the large one (ureter) leading to the bladder. This is a baglike organ in which the urine collects for a time and then is eliminated from the body through another tube (the urethra).

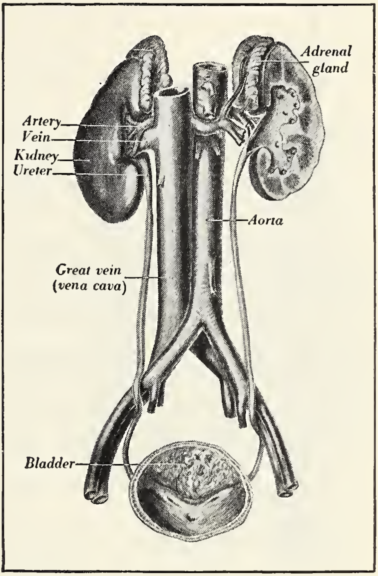


Fig. 232. The position and structure of the human kidneys. What excretory organs are not shown in this figure?

***The skin.** The skin is composed of an outer layer (epidermis) of dead cells covering and protecting the living cells beneath. Sweat glands are distributed over the body, to the number of more than two million. These glands consist each of a long coiled tube leading to an opening, or pore, in the skin (Fig. 233). They are most numerous in the palms of the hands and soles of the feet.

The sweat glands assist the kidneys in getting rid of excess water in the blood. Water containing waste materials from the blood passes from the capillaries into this tube and through it to the outside. Several pints of sweat, or perspiration, may be eliminated in one day. In addition to water the sweat consists of inorganic salts, the most abundant of which is common table salt (sodium chloride). It also contains smaller quantities of urea and of other organic salts.

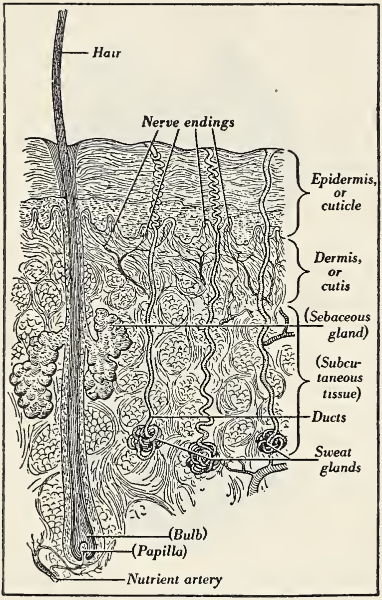


FIG. 233. What excretory organs other than the sweat glands does man have?

The chief function of sweat, however, is not to get rid of wastes but to regulate the temperature of the body by its evaporation. You will recall that heat is produced by the combustion of energy foods in the cells and by the friction of the muscles. Our bodies must always remain at a temperature of about 98.6° F. Hence excess heat must be eliminated. Heat is lost from our bodies in several ways: (1) by elimination with the products of excretion, since these waste products when eliminated are at the same temperature as the body; (2) by elimination with the air which is breathed from the lungs, and, since this air is nearly saturated with water vapor, the heat necessary to change the water to vapor is taken from the body; (3) by evaporation of sweat from the skin; (4) by radiation, convection, and conduction from the skin. About two thirds of the heat is removed by the last means, and more than half of the remainder by the evaporation of sweat.

Self-test on Problem XVII–C. **1.** Ammonium compounds in the blood must be changed into _ _(?)_ _.

2. The liver functions in changing _ _(?)_ _ compounds which are carried to it in the blood into urea.

3. The kidneys extract from the blood _ _(?)_ _ and other wastes.

4. Waste materials from worn-out red corpuscles are eliminated through the *alimentary canal.*

5. The kidneys are assisted by the _ _(?)_ _ in eliminating urea and other wastes.

6. The chief function of sweat is to *eliminate wastes.*

7. Name the four ways in which our bodies lose heat.

Self-test on Organization of Facts. List from this and preceding chapters all the organs which have to do with removing wastes from the body. Name the wastes removed by each.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Why does fanning oneself help to keep one cool?

2. How does drinking a sufficient amount of water help the kidneys to do their work?

3. In what way is the blood which leaves the kidneys different from the blood which is coming to them?

4. A case is known of a man who had no sweat glands. In summer he could do no work of any sort. Explain.

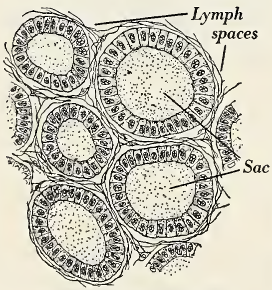
CHAPTER XVIII · Gland Secretions as Aids in the Use of Energy

Questions this Chapter Answers

How do glands take part in the division of labor?
What kinds of glands function in plants and animals?
What is the nature of hormones?
What are the nature and the important functions of the ductless glands in man?

Problem XVIII–A · What are Some Characteristics and Functions of the Various Glands in Man?

Cell chemistry and division of labor. We have learned that every living cell is a chemical laboratory. Raw materials are taken in, certain chemical changes take place, certain useful products are formed, and waste materials result. Every living cell carries on metabolism. Certain cells, however, not only engage in the usual cell activities but also perform special services which make life possible to the organism as a whole.



Portion of a ductless gland

FIG. 234. The cells secrete hormones into the closed sacs which they surround. The internal secretion then slowly finds its way out between the cells into the lymph. How do the secretions then reach the various parts of the body? (You may need to review portions of Chapter XV in order to answer this question)

***Kinds of glands and their functions.** In all but the simplest plants and animals certain structures called glands manufacture special substances needed by the organism. Glands are of two kinds: (1) the duct glands, or glands of external secretion; (2) the ductless glands, or glands of internal secretion (called also endocrine glands). The duct glands pour out their secretions through

tubes, or ducts. The ductless glands have no tubes or ducts; hence their secretions pass directly into the blood stream (Fig. 234).

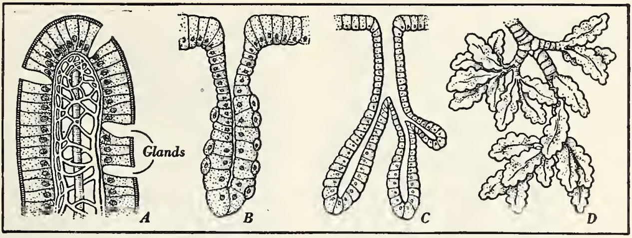


FIG. 235. Some typical duct glands. Is the sweat gland (Fig. 233, p. 356) a simple or a complex gland? Explain

The simplest glands are merely single cells. The mucous cells on the villi are single-celled glands of the duct type. Many-celled glands are of a variety of forms (Fig. 235). Some of the functions of special glands in plants are the manufacture of perfumes, flavors, waxes, and gums. Some of the more familiar functions of glands in animals are the manufacture of digestive juices, egg shells, shells which serve to cover the animal, milk for the young, and poisons for protection.

Most of the duct glands have been known for centuries. But practically nothing was known of the ductless glands a hundred years ago. Relatively little is yet known about the ductless glands, except that their secretions control the growth and development of the individual. Some study of ductless glands has been made in animals as low in the scale of life as fish. This chapter will discuss only some of the more important ductless glands and their special functions in human beings.

Human ductless glands and their functions. Ductless glands are located in various parts of the body (Fig. 236). Most of them are small, some not larger than a pea. The ones of which the functions are best understood are the thyroid gland and the parathyroid glands, located in the neck; the pineal gland and the pituitary gland, both located in the head; the adrenal (sometimes called the suprarenal) glands on the kidneys; and certain portions of the pancreas (called the islands of Langerhans). The secretions

of these glands, called hormones, passing into the blood stream are carried to every part of the body. They influence and regulate conditions of growth and development. Their activities exert considerable control over the rate of growth, the height and

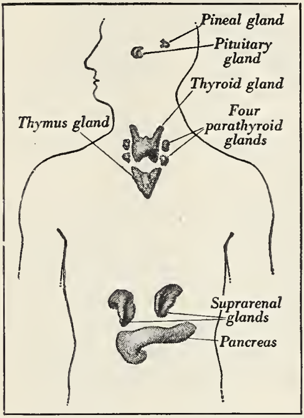
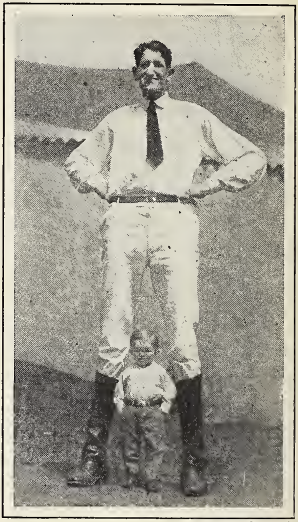


FIG. 236. All glands have a rich blood supply. Can you see why this rich blood supply is necessary?



H. A. Atwell Studio

FIG. 237. Extreme tallness or extreme shortness is sometimes due to a defective condition of which gland?

the general build of the body, the time at which one will mature, and how fat one will probably become. Each of the glands has its own special functions; yet all work more or less together as a connected system. Thus, if a certain gland becomes injured or ceases to function, one or more other glands may in some cases be able to take up its work. Usually, however, serious results follow the failure of any gland to perform its part in the division of labor.

We are interested in visiting circus side shows to see "The World's Fattest Man," "The Living Skeleton," "Tom Thumb," and "The Cardiff Giant." With few exceptions these are unfortunate people whose glandular systems are not functioning properly; hence their growth and development are not normal (Fig. 237).

The thyroid gland. The thyroid gland consists of two dark-red lobes, one on each side of the windpipe, joined by a strip of tissue (Fig. 238). The most important secretion of this gland is a hormone (thyroxin) which is composed of about 60 per cent iodine. Serious consequences result when too little or too much of this hormone is secreted. Too little may be produced for the reason that the food eaten does not furnish a sufficient supply of iodine salts to serve as raw material for the use of the gland. When this condition occurs, the thyroid enlarges, causing the swelling at the base of the neck called simple goiter (Fig. 183, p. 276). When, because of an inherited defect, the gland is unable to secrete a sufficient quantity of the hormone, the child fails to develop normally either physically or mentally (Fig. 239). Another result of the failure of the thyroid gland to secrete a sufficient quantity of its hormones is that a person often becomes very fat. If the lack of the hormones occurs later in life, other defects result. Sometimes the conditions caused by a deficiency of the thyroid hormones can be overcome in children and can be improved in adults if the sufferer is given thyroid extract. Taking this extract, however, is not a cure, since the extract cannot correct the defect in the gland itself. The sufferer must continue the treatment as long as he lives.

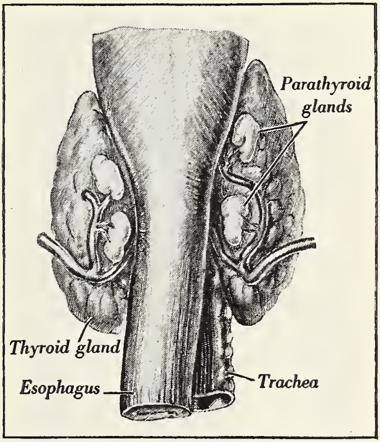


FIG. 238. Thyroid and parathyroid glands seen from the rear. Six glands are shown here. Explain

If too much of this thyroid hormone (thyroxin) passes into the blood stream, a serious disease (exophthalmic goiter) results. This is often successfully treated by surgery in which a part of the thyroid gland is removed.

An interesting experiment which shows that the hormones of the thyroid gland influence the development of a young animal has been performed with frog tadpoles. If the tadpole is fed thyroid extract, it develops very fast and becomes an adult in much less time than does a normally fed tadpole. But if the thyroid glands of a tadpole are removed, the tadpole never develops into a mature frog.

Fig. 239. A cretin. All children who suffer thus from lack of thyroid hormones have the same general appearance and characteristics. These two photographs are of the same child before and after treatment. Can you suggest how these changes were brought about?[1]

The four parathyroid glands. The parathyroid glands (Fig. 238) produce hormones which influence the nervous system and which control the assimilation of lime and phosphorus. Thus they affect the development and the structure of the teeth and bones. It is believed that they influence the development of the reproductive organs before birth.

The pineal gland. Some of the early investigators regarded the pineal gland as the seat of the human soul because it is located between the two halves of the brain. In some of the lower organisms this gland is developed into a rudimentary third eye. It is believed that this third eye was more perfectly developed in certain mud-burrowing creatures which became extinct millions of years ago. In man this gland is believed to influence the development of the brain and the reproductive organs.

[1] From N. B. Foster, "Diseases of the Thyroid Gland," in Nelson Loose-Leaf Living Medicine, Vol. III, by permission of Thomas Nelson & Sons.

The pituitary gland. The pituitary gland is composed of two lobes, each consisting of a different sort of tissue from the other and each having a totally different function from the other. A hormone produced by the front (anterior) lobe controls the growth of the bones. If too much of this hormone is produced, the person may grow to be a giant like those in the circus side shows (Fig. 237). If too little is produced, the child may be a dwarf, though in this case, unlike dwarfs produced by an insufficient amount of the thyroid hormone, he may be perfectly proportioned. The rear (posterior) lobe produces hormones which affect the activity of the nerve cells, of certain muscle cells, and of the kidneys; which regulate the growth of the reproductive organs; which contract the walls of the capillaries; and which, to some extent at least, regulate the amount of fat deposited in the tissues.

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FIG. 240. The supreme effort put forth in athletics is made possible by the secretions of what gland?

The adrenal glands. The hormone, adrenalin (or adrenin), produced by the adrenal glands, has marked effects upon the liver, the smooth muscles, and the circulatory system. When one is frightened, angry, or excited, the adrenal glands supply to the blood an unusually large amount of secretion. This, acting upon the liver, causes it to change some of its stored animal starch (glycogen) into sugar and to pour this into the blood stream. Thus an additional energy supply is available in case it is necessary to run, to fight, or to engage in unusual exertion. This secretion also causes a more rapid heartbeat and a greater blood pressure. At the same time it stops the digestive processes, thus sending more blood to the muscles and brain for use in the emer-

gency. The result is that one is capable of muscular feats which ordinarily could not be accomplished (Fig. 240).

Adrenalin has been analyzed by chemists and is now made artificially from coal tar. It is used in surgery to check excessive bleeding, to stimulate heart action, to reduce the effects of shock or to prevent the collapse of a patient after an operation, and to relieve asthma.

Organs which contain both duct glands and glands with internal secretions. 1. *The pancreas.* The pancreas was discussed in the chapter on digestion as an important digestive gland. It secretes certain enzymes which flow through its ducts into the small intestine. However, certain cells of the pancreas (the islands of Langerhans) do not pour their secretions into the ducts. These pass directly into the blood, as do the secretions of the ductless glands just discussed.

The hormone insulin, manufactured by the pancreas, controls the amount of sugar used by the cells of the body. It will be remembered from the discussion of circulation that digested carbohydrates pass into the blood as sugar. Passing with the blood to the liver, the excess sugar is stored in this organ as animal starch (glycogen), to be changed back again into sugar when needed. Insulin acts upon the liver to prevent it from changing its reserve starch into sugar when there is already sufficient sugar in the blood for the use of the cells. And insulin not only thus controls the amount of sugar in the blood, but also makes it possible for the cells to use sugar from the blood.

The disease diabetes results when the pancreas fails to supply the blood with a sufficient supply of insulin. The liver is not then prevented from transforming its stored animal starch into blood sugar. Moreover, because insulin is absent from the blood, the cells cannot assimilate the sugar which the circulation brings to them. The result is that the blood has an excess of sugar, which is excreted by the kidneys. Until recently there was no lasting help for one suffering from diabetes, except through control of the diet, chiefly by limiting the foods that supplied sugar. The disease was frequently fatal. In 1924 two Canadian scientists, Macleod and Banting, succeeded in preparing insulin from the pancreas of lower animals. When this insulin is injected into the blood of a

person who is suffering from diabetes, it functions just as if it had been manufactured by the pancreas in his own body. He is thus able to use the sugar in his body. The insulin treatment is not, however, a cure for diabetes. It does not remove the cause of the disease by restoring the pancreas to its normal activities. If the deficiency of the pancreas is permanent, the sufferer must continue the treatment as long as he lives.

2. *Certain cells in the small intestine.* The cells of the upper part of the small intestine pour certain secretions into the intestine and at the same time manufacture hormones. These start the digestive processes in the small intestine, thus: The food which leaves the stomach is acid in character, from the hydrochloric acid of the stomach. When this acid material comes in contact with the intestinal cells, these secrete a hormone (secretin) into the blood. When this hormone, carried by the circulation, reaches the pancreas, it stimulates the pancreas to secrete and to pour into the intestine the enzymes needed for the further digestion of the food.

3. *The reproductive glands.* The products of the reproductive glands make possible the survival of the race. These glands, however, have other important functions. Certain cells buried among the reproductive cells secrete hormones into the blood. These cells become active at about the time when a person approaches maturity. The hormones control the development of the male or the female characteristics. For example, a rooster develops a large comb, a plumed tail, and spurs, while the hen does not develop these conspicuous structures.

Self-test on Problem XVIII–A. **1.** *All* plants and animals have glands.

2. *Ductless* glands manufacture secretions which they pour out through tubes; *duct* glands manufacture secretions which they pour directly into the blood stream.

3. A gland *usually* consists of more than one cell.

4. Ductless glands have been studied in animals as low in the scale of life as the *highest invertebrates.*

5. The secretions of the various ductless glands are called (1) hormones; (2) electrons; (3) enzymes; (4) endocrines; (5) insulins; (6) thyroxin.

6. Match each word or expression under B with one and only one word or expression under A.

A	B
Gastric	Influence the pancreas
Thyroid	Growth of bones
Sex	Assimilation of lime and calcium
Parathyroid	Goiter
Pineal	Diabetes
Lymphatic	Development of brain
Pituitary	Releases energy needed in an emergency
Adrenal	
Salivary	
Pancreas	
Glands of small intestine	

ADDITIONAL EXERCISES AND ACTIVITIES

Review Exercise. A number of glands were discussed in the preceding chapters dealing with the physiological processes of plants and animals, especially of man. How many of these glands can you name and locate? Of how many of them can you briefly describe the special work, or function?

Special Reports. 1. Find out all you can about the discovery of insulin. (Consult a physiology textbook or an encyclopedia.)

2. Secure further information about any one of the ductless glands which especially interests you. (Consult a physiology textbook or an encyclopedia.)

3. Find, in zoology or physiology textbooks, examples of each of the four types of glands in Fig. 235.

Reference Books

Martin, E. G., and Weymouth, F. W. Elements of Physiology. Lea & Febiger, Philadelphia.

Sherman, H. C. Chemistry of Food and Nutrition. The Macmillan Company, New York.

Stiles, P. G. Human Physiology. W. B. Saunders Company, Philadelphia.

Unit V · *The Responses of Living Things to Energy and Other Factors in the Environment*

PROBLEMS DISCUSSED IN THIS UNIT

Suppose on a visit to the zoo one were to blow a shrill whistle in front of every cage. What would the animals do? One could accurately predict the ways in which many of them would behave. The birds would probably show fright; the lion could be expected to look intently about; the snakes would be almost certain to do nothing. Suppose the experiment were extended to include trying the effects of a wide variety of sights, sounds, and other influences upon all kinds of living things. Suppose one should attempt even to find out how simple animals respond and whether any sort of influence would change the behavior of the simplest animals and the plants.

This unit discusses why and how living things behave as they do. These major problems are considered:

- How are living things affected by various influences or conditions in their surroundings?
- What kinds of responses are plants and untrained animals ordinarily able to make?
- How are living things equipped to make these responses?
- What kinds of responses can animals learn to make?
- What is the nature of each of the special sense organs of living things?

Chapter XIX · Unlearned Responses

Questions this Chapter Answers

How are living things affected by various influences or conditions in their surroundings?

What kinds of responses to influences in the environment are made by plants and animals?

How do special sense organs aid various animals in the struggle for survival?

What is the structure and what are the functions of the human nervous system?

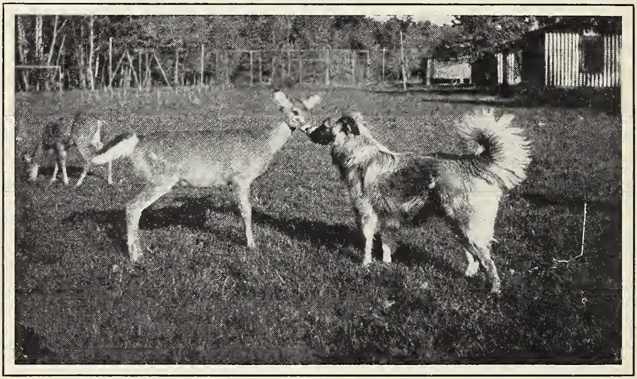

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Fig. 241. How does this picture illustrate irritability?

Problem XIX–A · What Responses can be Made by Plants and by Protozoa?

Responses to stimuli. Living things all have the ability to respond to their environments. This ability is one of the differences between living and nonliving things. Nonliving things are not aware of their surroundings and cannot of themselves react[1]

[1] *React* (re akt′): to act in response to a stimulus, or influence. Any influence or condition to which a living thing responds is a *stimulus* (stim′u lus), plural *stimuli* (stim′u li). The response to a stimulus is a *reaction.*

to the changes in them. Therefore we say that living things are sensitive, or irritable (Fig. 241), because they respond, or react, to temperature, touch (or contact), light, electricity, chemical substances, and various other stimuli. A reaction may be considered a successful one if it aids the organism directly or indirectly to secure or to conserve energy.

FIG. 242. What statement in the text does this picture illustrate?

Living things, moreover, differ in the kinds of stimuli to which they are able to respond. Your dog may come when you call to him; but an earthworm could not respond to the stimulus of sound, because it has neither organs for hearing nor the sort of brain by which it could understand what it heard. A wolf would be able to smell meat when too far away to see it. A crow, however, would need to see the meat in order to find it.

Different sorts of living things react to the same stimulus in very different ways. A cat would show no interest in a fishing pole but would probably want to eat a raw fish. A boy, however, would probably be enthusiastic over a fishing pole but usually would not be interested in a raw fish as food (Fig. 242).

Responses of plants to stimuli. All but the simplest plants have some structures which are especially adapted to receiving stimuli. A few experiments will indicate the nature of these plant reactions.

Experiment 74. Does gravity always influence roots to grow downward and stems to grow upward? Make a "pocket garden" in the following manner: Secure two pieces of glass about five inches square. On one place several layers of blotting paper, paper toweling, or other material that will hold moisture. Around the edges of the plate place on the glass some quarter-inch strips of wood to support the second square of glass. Then on the wet paper put in various positions four or five corn or oat grains or other seeds which have soaked for several hours. Cover these with the second glass square and fasten the entire

apparatus securely together by putting gummed tape or paper around the edges. Stand the "pocket garden" on edge and examine it from day to day. Keep it moist. When the seeds begin to germinate, note whether or not the roots all grow downward. Turn the garden completely over, standing it on the opposite edge from that on which it first rested. Do the roots continue to grow in the direction in which they started, or do they again turn downward? In what direction do the stems grow?

***Exercise on scientific method* (*using controls*).** Why were several seeds used in this experiment instead of one? Explain how the different grains served as controls.

As was stated earlier all organisms must have water for continued life. The stimulus of water, then, is one to which all living things respond. Most plants show a marked tendency to send roots in the direction of a water supply. Desert plants frequently have roots many feet long. Alfalfa grown in dry regions has been known to produce nearly vertical roots fifteen feet long. In our city streets drain pipes are sometimes choked or burst by roots which grow through cracks in the pipes in their search for water. Some cities prohibit the planting of such trees as poplars because of this tendency.

In connection with the food-making activities of plants, we learned that many adaptations of leaves and stems enable these parts to secure the greatest possible amount of light. Light, then, is another stimulus which causes a plant to behave in a certain way. Some plants exhibit sleep movements, which are responses to darkness or to decreasing light. The flowers or leaves of such plants close at night. The leaves of some kinds of clover act in this way, folding together and drooping along the stem.

Responses of animals which have no specialized structures. In the simplest animals, the Protozoa, there can, of course, be no special organs concerned with receiving stimuli or with making responses. Yet such animals respond to a variety of stimuli in definite ways which normally do not vary. If, for example, an amœba is touched, it contracts and remains motionless for some time. When it encounters a bit of material that might furnish food, the protoplasm flows around the particle and engulfs it. If one side of a drop of water containing an amœba is strongly

heated, the animal moves away from the warmer part. An amœba will also move away from a bright light thrown on the water.

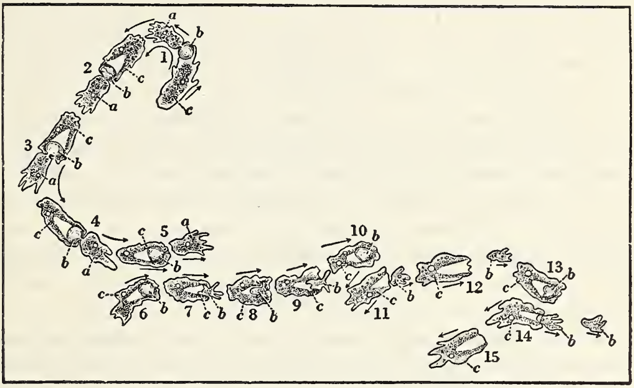


FIG. 243. An unexplained response. The behavior of even the simplest animals is sometimes amazing. Jennings, a prominent and trusted American biologist, observed a large amœba pursue a smaller one and finally succeed in pinching off and engulfing part of it. Several times the part swallowed tried to escape through an opening in the protoplasm of the larger one, but each time was prevented by the surrounding movements of the latter. Finally it succeeded in escaping completely, only to be pursued and again captured. The small bit of amœba then contracted into a ball and stayed still until, in crawling about, the larger one left only a thin layer of protoplasm covering it. The prisoner then quickly forced its way through the thin wall and escaped. In accepting the account of this observation, which of the scientific attitudes (pp. 12–13) do scientists illustrate?[1]

Apparently the animal is sensitive to chemical changes too, for it will retreat from a drop of salt water (Fig. 243). Other Protozoa have reactions more or less like those of an amœba. *Paramecium* will swim away from salt added to the water, but will swim into a drop of weak acid and stay there.

Simplest reactions called tropisms. The kinds of reactions of plants and one-celled animals which have just been described are called tropisms. A tropism is the simplest reaction to a stimulus. It is not an act which the organism has learned to perform or can learn to perform. The organism inherits the ability to react in a

[1] After Jennings's *Behavior of the Lower Organisms.*

certain way to a certain stimulus, and it normally reacts in no other way to that same stimulus.

The word *tropism* means "a turning." Hence a tropism is the turning of part or all of the organism toward or away from the influence, or stimulus. If the organism or its part moves toward the stimulus, the tropism is a positive one. If the movement is away from the stimulus, the tropism is a negative one. Thus plant roots have a positive tropism toward the earth and toward water, while plant stems have a negative tropism toward the earth and a positive one toward light. The plants and the simplest animals can make no responses to stimuli other than tropisms.[1] But more complex animals, even some as high in the scale of life as birds, have tropisms. For example, if a captured wild bird is given its freedom in a room, it will usually fly directly to a window.

If in avoiding an unfavorable stimulus the organism happens to reach a place where the conditions are more favorable to its life, it survives. But if it happens to reach an environment which is unfavorable, it may die. In general, however, tropisms have survival values to the organisms performing them. For example, an amœba avoids stimuli such as extreme heat and strong chemicals, which might injure it, and moves toward food. Sometimes, however, the tropism results in the death of the organism. Sea birds flying after sunset near a lighthouse sometimes fly straight toward the light, killing themselves against the lamp tower.

Experiment 75. Do certain animals, such as millepedes, spiders, or beetles, show a positive or a negative tropism toward light? Place the animal in a darkened space of which some parts are darker than others. Turn the light from a flashlight upon the animal and watch its reaction. Answer with a complete sentence the question asked at the beginning of this experiment.

[1] Among the different tropisms are these: (1) chemotropism, a reaction to some chemicals; (2) electrotropism, a reaction to electric current; (3) phototropism, a reaction to light; (4) heliotropism, a reaction to the sun; (5) thigmotropism, a reaction to contact; (6) thermotropism, a reaction to heat energy; (7) geotropism, a reaction to gravity; (8) rheotropism, a reaction to a current of water; (9) chromotropism, a reaction to color; (10) hydrotropism, a reaction to water. Some recent investigations give results which seem to indicate that all tropisms are negative and that a turning toward a stimulus is really a turning away from the opposite stimulus. Thus what would seem like a turning toward light would be a turning away from darkness.

Self-test on Problem XIX–A. 1. An animal is irritable if it (1) gets angry easily; (2) scratches itself; (3) is partly deaf; (4) changes its behavior in accordance with changes in the environment; (5) carries on the process of metabolism.

2. Bacteria have *rudimentary* sense organs.

3. The *leaves* of most plants grow in the direction of water.

4. *No* Protozoa are irritable.

5. It is *difficult* for any living thing to learn to perform a tropism.

6. Trees and flowering plants have *few* reactions other than tropisms.

7. Tropisms are *always* an aid to the survival of an organism.

Problem XIX–B · How do Organisms with Nervous Systems React to Stimuli?

The nervous systems of simpler animals. With the plants and the one-celled animals, the organism as a whole or a considerable portion of it receives the stimulus and reacts to it. Most of the many-celled animals, however, have certain cells, called nerve cells, or neurons, which are particularly well fitted for receiving impressions from the outside world and which together make up a nervous system. Where these nerve cells are very simple, the kinds of impressions which they can receive are few, and the reaction of the animal to the stimulus, that is, its behavior, is always the same.

In general the more primitive the animal, the more primitive is its nervous system. Thus the sponge has no true nerves. Some of its body cells, however, are modified to receive stimuli and to carry impulses to the parts of its body near the point where the stimulus is received. *Hydra*, a somewhat more complex animal, has true nerve cells, or neurons, in both outer and inner layers. These are joined throughout the body to form a nerve net (Fig. 244). The starfish represents a further advance. It has neurons grouped in definite parts of its body rather than scattered throughout. Most of the nerve tissue is in a ring around the mouth. The earthworm has a higher development, a simple brain made up of a mass of neurons at one end of the body. It has other smaller masses of nerve cells, called ganglia (singular, ganglion), in each segment.

***Nerve cells.** The nerve cell, or neuron, is like any other cell in being made up of protoplasm and in containing a nucleus. It

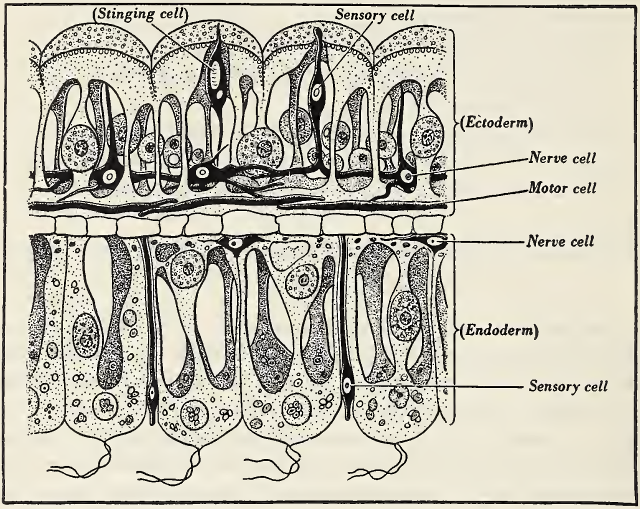


FIG. 244. The nerve net of a hydra. Can you explain how it is possible for the whole body of a hydra to contract when one tentacle is touched?

differs, however, in being very irregular in shape, with many short branches, called *dendrites*, and usually one long branch, called an *axon*. A neuron which receives an impression, or stimulus, and carries it toward the brain is called a *sensory neuron*. A neuron which carries an impulse from the brain or the spinal cord to a gland or a muscle is called a *motor neuron*. A third type serves to relay impulses from a sensory to a motor nerve or vice versa.

A stimulus travels over a neuron in one direction only — from the branches of the dendrite (Fig. 245) through the cell body or nucleus, and thence along the axon to its end brush.

With simple animals, such as *Hydra*, a single nerve cell may serve both to receive the stimulus and to carry that stimulus directly to a muscle cell. In most cases, however, even with the simpler animals, two or more nerve cells are necessary for a reac-

tion. The dendrites of the receiving end of the sensory nerve receive the stimulus at the surface of the body. The impulse then travels along the axon to the end of the sensory nerve cell. Here it passes to the dendrites of a motor nerve cell. The impulse continues along this motor nerve to the end which is attached to a muscle. Thus the stimulus received by a sensory nerve results in a reaction of a muscle some distance from the point where the impulse was received. Sometimes the impulse may pass from the first nerve end to several others, and may thus at the same instant reach several motor nerves connected with different muscles.

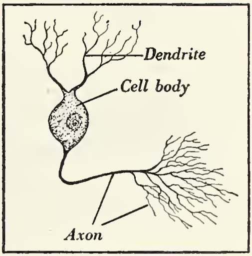


Fig. 245. A nerve cell, or neuron. What has been said in an earlier chapter concerning the size of neurons?

Reactions of simple animals. The possession of a nerve net makes it possible for *Hydra* to perform somewhat more complex reactions to stimuli than are possible with plants and the Protozoa, which have no nervous systems whatever, or the sponge, which has very primitive nerve cells. Nevertheless the responses of *Hydra* are chiefly tropisms. Like plants and the Protozoa it responds to temperature, electric current, light, and other stimuli. Its more complex reactions, such as its movement of one part in response to the stimulus applied to another part, are called *reflex actions*, or *reflexes*. It must be remembered, however, that there is no essential difference between a tropism and a reflex. Both are unlearned reactions. Both are inherited. Both are automatic; that is, the response to a given stimulus is nearly always the same.

The reactions of the starfish are tropisms and simple reflexes, similar to those of still lower forms of life. An example of its tropisms is its reaction to light. It usually hides on the undersurface of a rock or in a crevice during the daytime and travels about actively at night. An example of its simple reflexes is its efforts to keep right side up. If a starfish is put on its "back," with its tube feet up, it bends its arms and by pushing against a rock turns over.

The earthworm has simple reflex reactions. For example, crawling is the result of a series of reflexes, the first of which is

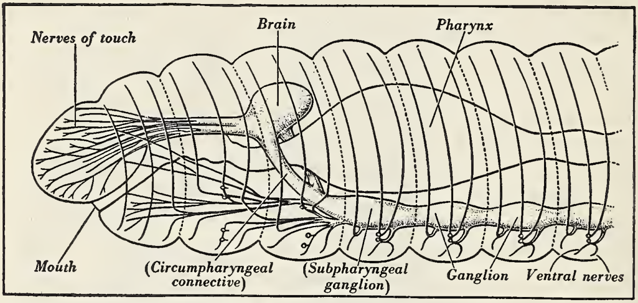


FIG. 246. Nervous system of an earthworm. In what respects does this nervous system mark an advance over that of *Hydra*?

started by a stimulus such as a touch or a bright light. The other reflexes in the series follow in turn, each being stimulated by the action of the preceding one.

It is evident that the nervous system of the earthworm is more complex than that of any of the other organisms described earlier in this chapter. Most of the earthworm's reactions to stimuli, however, are simple tropisms and reflexes such as those that simpler organisms show. But the worm is capable of a still more complex type of nervous reaction. This is illustrated by its method of making a burrow in the ground. All the earthworms that we know about make their burrows in almost exactly the same way. Of course they have not been taught by their parents how to make a burrow, nor have they ever seen one made. The making of a burrow is a fairly complex process. In order to be able to make one the earthworm must have a fairly complex nervous system (Fig. 246). This inherited equipment of nerves enables the worm to make its burrow in a certain way with very little possible variation.[1] The behavior which results from such an inherited equipment of nerves is called an instinct.

Experiment 76. To what stimuli other than those described in the preceding paragraphs does an earthworm seem sensitive? Place a live

[1] *Variation* (va ri a'shun): the act or condition of varying, or changing.

earthworm on moist sand or dirt in a box. What does it do? What stimuli do you think make it act so? When the worm is quiet, tap sharply on the side of the box. What does the worm do? Touch various parts of its body with your pencil. Are all parts equally sensitive to touch?

Reactions of animals having special sense organs. In most of the many-celled animals, cells at the surface have become more or less highly specialized for receiving impressions of the world outside. These cells make up the special sense organs, such as those for touch, seeing, hearing, smelling, and tasting. These organs as found in different animals vary greatly in the form and the complexity of their structures and in their sensitiveness to the stimuli they are fitted to receive.

***Summary comparison of tropisms, reflexes, and instincts.** Tropisms, reflexes, and instincts are not essentially different. Moreover, there is no clear dividing line between a tropism and a reflex or between a reflex and an instinct. For example, one scientist might call the flight of birds toward a bright light (mentioned earlier in this chapter) a tropism; another might call it a reflex; and perhaps still another might call it an instinct.

Tropisms, reflexes, and instincts are alike in being inherited and unlearned. A tropism, however, is in general somewhat simpler than a reflex, and a reflex is in general somewhat simpler than an instinct. Furthermore, a tropism is somewhat more definitely fixed and automatic than a reflex, and a reflex is more definitely fixed and automatic than an instinct. In other words, higher types of response are in general more easily modified than lower types. For example, birds inherit the instinct to build nests. Each species builds its nests in the same general form, in the same sort of location, and in general of the same sorts of materials. But if a bird cannot find the customary location or materials, it will use the best substitute it can find (Fig. 247). In one unusual case a robin built her nest and raised her young on a traveling crane in a shipyard. Returning with food for her brood, she flew to the crane in whatever part of the yard it happened to be, paying no heed to the uproar and confusion about her.

While it is true that instincts, such as nest-building, can be modified considerably, it must not be concluded that only instincts

can be modified. In the next chapter it will be shown that with animals reflexes and even in some cases tropisms can be modified somewhat by experience.

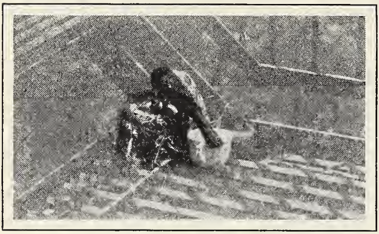


Fig. 247. A robin nest on a fire escape. What modification of an instinct is shown here?

Tropisms, reflexes, and instincts must not be confused with such bodily actions as those of digestion, heartbeat, breathing, and elimination. These also are automatic and involuntary. They continue during the life of the organism, no matter what its activities or environment may be. They can be modified for a time, as when a person holds his breath, but such modification is only temporary. On the other hand, when a reflex or an instinct has become modified, the modification is usually permanent.

Self-test on Problem XIX–B. **1.** The simplest animals have *simple* nerves.

2. The *more* simple the nervous system, the *less* simple the possible reactions it can have.

3. In general the higher the animal, the less *complex* is its nervous system.

4. Stimuli are carried to the brain, and from the brain to muscles, by means of __(?)__.

5. A *motor* nerve may connect with several *sensory* nerves.

6. Scratching a mosquito bite is an example of (1) a tropism; (2) a reflex; (3) an instinct; (4) a learned reaction; (5) continued learning.

7. The building of a dam by a beaver is an example of __(?)__.

8. It would be easier to modify such a *tropism* as the building of a honeycomb by a bee than such a *reflex* as a moth's flying toward a light.

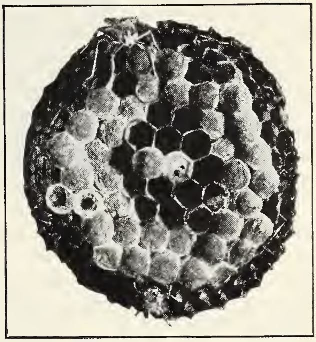
9. *All* types of reaction are capable of being modified more or less.

10. If a bird were taught to build its nest in a new way, that bird would in future be likely to build its nests in the *old* way.

11. *Few* of the simplest animals have special sense organs.

Problem XIX–C · What Responses can Insects Make?

The nervous system of an insect. Since the insects are considered to be man's most successful competitors in the struggle for existence, we should expect to find these animals well equipped to adjust themselves to the world about them. If you have ever tried to capture a grasshopper or a fly, you know it very readily becomes sensitive to your approach and is able to react quickly.



Cornelia Clarke

FIG. 248. Nest of *Polistes* wasp. Does the wasp learn how to make its nest? Explain.

The nervous system of an insect is not so very different in appearance from that of an earthworm. The organization of this nervous system, however, is more complex and more efficient, partly because of the numerous sense organs. There is a double nerve cord extending along the lower body wall, with ganglia in eight of the segments, and there is a brain in the head.

Most of the organs of special sense are located on the head. This arrangement marks a distinct advance over the nerve equipments of simpler animals, since it makes it possible for an animal which moves head foremost to learn most readily what it is about to encounter. Because of its more highly organized nervous system, an insect is more fully aware of its environment and can react to it in more different ways than can simpler animals.

The reactions of insects. Many of the actions of insects are tropisms. For example, if all but one window of a room are darkened, the flies in the room will collect at that window. If an insect like a ladybird beetle is picked up on a stick, it will crawl to the top of the stick. If the stick is then turned around, the insect will again crawl toward the top.

Other sorts of behavior which we observe in insects are reflexes, as when a fly moves quickly when a person moves to strike

it. More complex responses of an insect may be termed instincts (Fig. 248). A honeybee makes comb like that made by all other bees of the same species. The tiny silkworm larva will hunt out the mulberry leaves on which it feeds and will refuse other kinds of leaves. A fly will instinctively lay its eggs on decaying organic matter, which will serve as food for its young (Fig. 249).

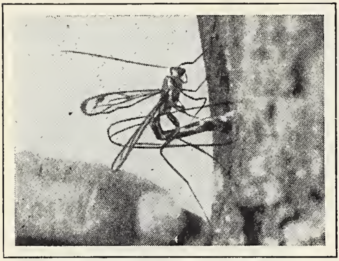


Fig. 249. A complex instinct. "This insect . . . is drilling into hard maple wood for the purpose of laying an egg in the burrow of a wood-boring larva. How long she had been there before I found her it is impossible to state, but for more than two hours she worked, inserting and partially withdrawing her drill repeatedly until it had penetrated nearly two inches into the hard wood. At last she withdrew the drill, apparently satisfied, and flew away, to save more maple trees from borers, I hope."[1] How do you explain the ichneumon fly's behavior?

Often the instinctive actions of insects seem so complex that it is difficult to think of them as being purely mechanical reactions, as they are. The actions of a certain larva which is a parasite of one of the wild solitary bees illustrates this statement. Following their inherited instincts these tiny larvæ lie in wait for this certain kind of bee at the mouth of the underground tunnel in which she builds her nest. As she approaches, several of the larvæ leap upon her back and bury themselves in her hair. Here they remain motionless while the bee, following her instincts, makes the necessary journeys to the flowers for materials with which to construct her cells and to store them with food for her young. But the instant she lays an egg in a cell, the egg somehow serves as a stimulus to the tiny parasites, causing them to leap upon it, for it is the bee's egg which they must have for food. The bee seals the cell in her customary mechanical way — the only way which her inherited nerve structure permits. She has no way of knowing that her egg will be eaten, and could not alter her behavior in the slightest degree even if she did.

[1] From Clifton H. Hodge's *Nature Study and Life.* Ginn and Company, 1902.

Another example of the instinctive behavior of insects may seem even more remarkable. A German investigator placed in several saucers various kinds of sweet substances upon which he thought the honeybees might feed. Soon a passing bee stopped to investigate. It seemed to like best a dish of honey and water. Finally it flew away, back to the hive. Before long it returned, followed shortly by other bees, until many of the insects were engaged in transferring the honey to the comb. Evidently the bees had somehow been able to learn of the discovery made by the first bee. How they did this, the investigator was not able to discover. At last the supply of honey was exhausted. The bees stopped coming almost as suddenly as they had appeared. Somehow they had discovered, without each one's investigating, that all the food was gone.

We must not interpret these actions as thinking or remembering in the same sense that man thinks and remembers. The actions of the bees were purely mechanical and in response to stimuli which the observer was unable to detect.

Self-test on Problem XIX–C. **1.** Insects have *fewer* sense organs than an annelid, such as the earthworm.

2. Unlike the lower organisms, the insects have most of their sense organs on their *legs*.

3. *Most* reactions of insects are unlearned, automatic, and not easily modified.

4. The care given to certain plant lice ("ant cows") by ants is an example of *a reflex*.

5. The biting movements of the jaws of an ant when it is seized furnish an example of a *tropism*.

6. The crawling of an ant away from something hot is an example of a *reflex*.

Problem XIX–D · What Responses can Chordates Make?

The nervous system of a chordate. The development of an internal skeleton makes possible a more complex and delicate nervous system. The spinal cord of the vertebrate is inclosed and protected in the vertebral[1] column, instead of merely lying along

[1]*Vertebral* (vur'te bral): pertaining to the vertebræ.

the lower side of the body cavity as the nerve cord does in insects and other invertebrates. And the brain is inclosed and protected in the skull.

In the preceding sections it was shown that as far down in the scale of life as the earthworm, there is the beginning of a brain, though in its most primitive form such a brain is merely the largest of several ganglia, or masses of nerve cells. The brain of the insect, which is the highest of the invertebrates, is a complex ganglion of two lobes with many nerve connections to special sense organs and to the various parts of the body. Yet the insect brain is relatively simple compared with that of the lowest vertebrates. The rest of the nervous structure of the insect is likewise simple when compared with the several complex systems of vertebrates.

*The central nervous system of higher animals is composed of a brain, a spinal cord, and the nerves branching from them. Ten to twelve pairs of nerves (the peripheral nerves), each composed of many fibers, branch to various parts of the body from the brain. Other similar pairs of nerves pass out between the vertebræ from the spinal cord to all parts of the body. A chain of ganglia, making up the sympathetic nervous system, extends on each side of the spinal cord and connects at various points with the brain and the spinal cord. This increasing complexity of structure in the vertebrates makes possible a higher order of adjustment, thus enabling them to survive in a highly complex environment.

The brain and spinal cord of the frog are sufficiently typical of similar organs of other vertebrates to serve for study.

Experiment 77. What are the parts of the nervous system of the frog? Place a frog in a jar with some cotton soaked in ether or chloroform. Cover the jar tightly and leave it for ten or more minutes until the frog is dead. Or use the frog you saved from earlier experiments. Open the body by cutting the muscles along the underside. Remove the internal organs. Along the back find several large white cords which come from between the vertebræ of the spinal column. These are nerves. Trace them for some distance. Where do they go? What muscles do they control? Now turn the frog over, so that you are looking at the top of its head. Remove the bone carefully from the top of the skull, exposing the brain cavity. Notice the membrane covering the brain. Can you find blood vessels in this membrane? Locate the parts of the brain by consulting Fig. 250.

The most important parts of the frog's brain are the olfactory lobes, the cerebrum, the optic lobes, the cerebellum, and the medulla (medulla oblongata). The olfactory lobes carry sense impressions from the nose. The function of the cerebrum of the frog is not yet certainly known. In the higher animals the cerebrum controls the voluntary actions, that is, those having to do with the will, or intention, and the intelligence. The optic lobes have some influence on reflex actions and also control vision. The medulla of the frog, which is merely a broadening of the spinal cord, controls most of the essential life processes, such as breathing, eating, heartbeat, and the simple reflexes in general, such as swimming and jumping.

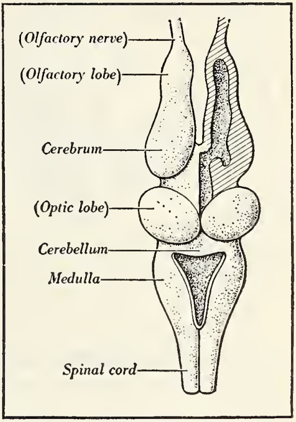


FIG. 250. Frog's brain. Self-test on Mastery of Facts: For how many of the structures named here can you suggest functions?

The frog is capable of some of the same kinds of nervous reactions as are the simpler organisms. It has tropisms. An example is its reaction to light, to which both its eyes and its skin are sensitive. And it has many reflexes or instinctive acts, such as swimming and jumping or diving when touched or when it hears a sudden sound. Most of its reactions are instinctive, unlearned behaviors such as the invertebrates show. Yet because it possesses a true brain, with a small but definite cerebrum, there are many more possible responses to a stimulus than in the simpler animals. A reason is that there are more cells in the brain and hence more possible connections between sensory nerves and motor nerves. Thus, if a frog were sitting on a lily pad when a bird came near, the sensory nerves of the eyes would send to the brain information concerning this possible danger. The frog could react in several ways, depending on what set of muscles received the command to move. It might lie flat on the leaf to escape being seen. It might slide quietly off the leaf into the water, or it might jump.

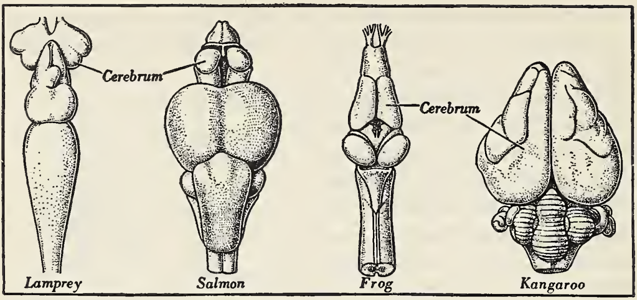


FIG. 251. Brains of typical chordates: *A*, lamprey; *B*, salmon; *C*, frog; *D*, kangaroo. Should you expect the cerebrum of the human brain to be larger or smaller in relation to the rest of the brain than that of some or any of these?

The nervous system of man. If we were to study other vertebrates, we should find an increasing size of brain as we progressed up the scale of life (Fig. 251). The more intelligent the animal, in general, the greater the size of the cerebrum in comparison with the other parts of the brain.

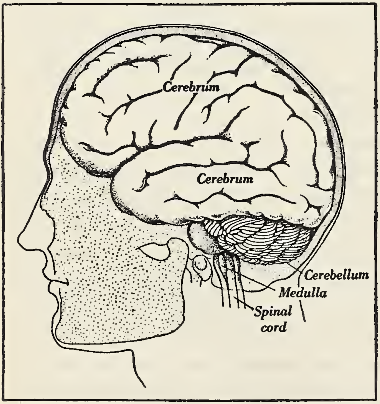


FIG. 252. Brain of man. State the chief functions of each of the parts of the nervous system labeled here

The nervous system of man is much the same as that of the frog. The functions of different parts of the nervous system are known in only a general way. Exactly how any of these functions is carried out is not yet known. The cerebrum (Fig. 252) controls voluntary actions and our remembering and thinking. It is also believed to be the seat of the special senses. The cerebellum is thought to serve in coördinating the

action of muscles, that is, in making them work together. For example, there are dozens of muscles used in walking. If they did

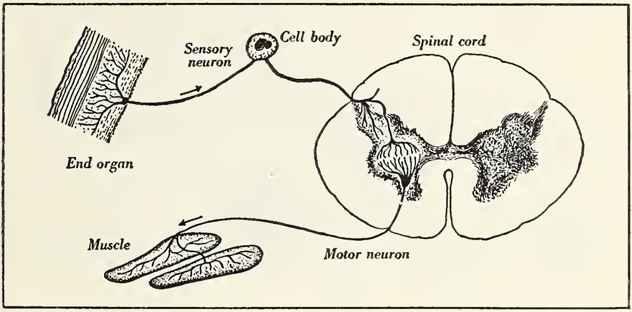


Fig. 253. A reflex arc. How does this figure help to explain Fig. 254?

not all work together properly, one could not walk. The medulla is the seat of such involuntary movements as those connected with the beating of the heart and breathing. Through it pass many nerves to the spinal cord.

The spinal cord extends from the base of the brain almost to the end of the backbone. It serves not only to convey nervous impulses between the brain and all parts of the body but also to control many of the reflexes, such as dodging, leaping from danger, coughing, and the like (Fig. 253). The fact that simple reflexes can be carried on through the spinal cord without requiring the help of the brain has great survival value (Fig. 254). Although impulses pass along nerves at the rate of from about half a foot to three hundred feet per second, nevertheless *some* time is required for a nerve impulse to pass up the spinal cord to the cerebrum and back to the motor nerves. When the reflex is controlled by the spinal cord, this time is saved. Thus it might be impossible to leap to safety from a falling tree if one had to wait to think about how and where to jump.

Man inherits reflexes and instincts, just as other animals do. That is, the response he will ordinarily make to a stimulus is already determined by the close connection between the sensory nerves receiving the stimulus and the motor nerves governing the

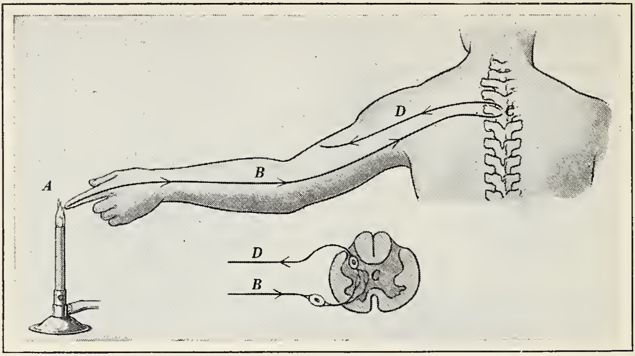


FIG. 254. Can you explain this diagram? See text

response to it. Any action which is involuntary and unlearned is really a reflex. Thus, if a baby starts to fall, it will instinctively clutch at something for support. So strong is this clutching impulse that a newborn baby can hold to something and support its entire weight. One instinctively fears sudden loud noises, though one may learn to modify this instinctive fear.

Essential activities go on in our bodies without any voluntary control, for example, actions concerned with the circulation of the blood, the digestion of food, the work of glands, excretion, and many other functions. These movements are controlled by the sympathetic nervous system working in harmony with the medulla and the cerebrum. The nerves making up this system are located in ganglia distributed along each side of the spinal column (Fig. 255).

Alcohol, tobacco, and the nervous system. Alcohol acts directly upon the nervous system, affecting the coverings of the neurons and thus interfering with their normal functioning. Generally, drinking at first causes nervous excitement which, if the drinking is continued, changes to a stupor or even to unconsciousness. A person under the influence of alcohol is deprived to a greater or smaller extent of his ability to perform the highest intellectual tasks effectively. He is also unable to control his nerves and

muscles effectively in performing tasks demanding speed and accuracy. Therefore even moderate drinking has been found sufficient to prevent athletes from making their best performances. Furthermore, moderate drinking is often the cause of serious automobile accidents.

In a similar way the use of tobacco has been found to be associated with reduction of efficiency of high-school students in athletics and in scholarship.

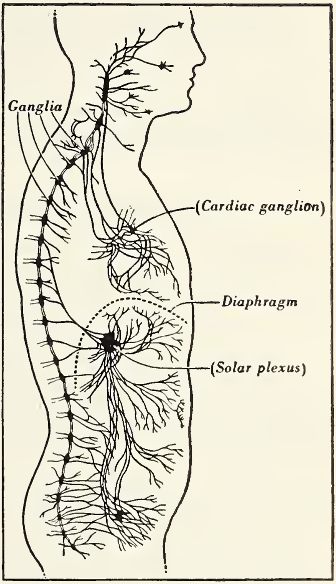


FIG. 255. Diagram of sympathetic nervous system. With what activities is the sympathetic nervous system concerned?

Self-test on Problem XIX–D.

1. Animals with simple brains are found as low in the scale of life as the (1) arthropods; (2) annelids; (3) Porifera; (4) chordates; (5) Protozoa; (6) mollusks.

2. A fish, such as the trout, has a *less complex* brain than an ant.

3. The central nervous system of man is composed of a __(?)__, __(?)__, and __(?)__.

4. In addition to the central nervous system, higher animals have a __(?)__ nervous system.

5. The *medulla* of a higher animal controls such reactions as deciding to fight, to run, or to hide.

6. The *brain* of a man is larger compared with the rest of his nervous system than is the brain of an elephant or a whale.

7. Such actions as the use of both hands in lifting an object are believed to be controlled by the *cerebrum.*

8. Such involuntary movements as blinking the eye are controlled by the *cerebrum.*

9. Man's chances for survival would be *increased* if his reflexes were controlled by the cerebrum instead of by the *cerebellum,* as is now the case.

10. Jumping when there is a sudden loud sound is an example of *instinct.*

11. Alcohol and tobacco are of *small benefit* to the nervous system.

Self-test on Biological Principles. **1.** Can you explain this statement: "Tropisms, reflexes, and instincts differ in degree rather than in kind"?

2. What evidence can you give from this chapter which supports the principle "Increased complexity of structure goes hand in hand with division of labor"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Florists sometimes tell us that our house plants will grow much more vigorously if we water them by standing the flowerpots in water rather than by pouring water on from above. Can you explain why this statement is usually true?

2. Summarize the ways in which tropisms are of value to a plant.

3. A baby beaver raised as a pet in a city home far from its native habitat tried to build a dam across the living-room floor, using various objects which it had collected about the house. How would you explain this behavior?

4. Why is a blow at the base of the skull more liable to cause death than one on the top of the skull?

Special Reports. **1.** What is a compass plant? Why is it so called? (Consult an advanced botany textbook or an encyclopedia.)

2. Look up in an advanced biology or zoology textbook the story of the relations of the *Pronuba* moth and the yucca. Does the moth act intelligently? Explain.

3. Look up in one of the many insect books by the great French naturalist Fabre some accounts of instinctive action.

Chapter XX · Learned Responses

Questions this Chapter Answers

How is learning related to experience?
What are the factors of learning?
What is meant by memory ideas?
How are habits formed?
Can older people continue to learn?
Is it true that if one is able to do certain things well, one probably will be unable to do other things well?
What are some of the advantages of a long period of infancy?

Problem XX–A · What are Some Factors in Animal Learning?

Learning results from experience. The important difference between an unlearned response and a learned response is that the learned response is gained through experience. Some practice in making certain responses is often necessary in bringing to complete development some of the simpler instinctive reactions, such as those having to do with feeding, flying, swimming, and the like. For example, two baby meadow larks taken from the nest when very young and brought up by hand had to learn to eat when they had developed sufficiently so that they no longer needed to have food put into their mouths. At the sight of an earthworm placed on the ground in front of them, they immediately began pecking, automatically, with their bodies stiff. Sometimes they hit the worm with their beaks, but often at first they did not. They improved rapidly, however, and before long could pick up and eat a worm or an insect as expertly as could an adult bird.

Learning of this type may be explained thus: The young birds when hatched were equipped with nerves which enabled them to make the pecking motions when they saw the food. But they needed practice in perfecting the movements. At first the impulse might go to muscles which did not produce the desired response, that of seizing the worm. These movements did not give satisfaction, while those which resulted in seizing the worm did. Little

Newton H. Hartman

FIG. 256. Lion cub and pup, each three months old, Philadelphia zoo. In what respect is learning taking place?

by little the useless and therefore unsatisfactory movements were eliminated. There remained only the response which brought satisfaction in securing the worm.

This type of learning, which makes some instinctive action perfect through practice, is found in all animals that have complex instinctive nerve patterns. The human baby reaches for a bright object but must learn through experience when the object is near enough to be grasped. Such learning, however, is not true learning in the sense that the animal acquires some response totally new and different from any which it would ordinarily make (Fig. 256). The rest of this chapter will be concerned with the learning of responses different from tropisms, reflexes, and instincts, which are inherited.

Learning consists in modifying responses. Some sort of true learning is possible with animals very low in the scale of life. Scientists report that even amœbas and paramecia have been observed to modify their usual responses in such a way as to indicate possible learning. For example, two investigators directed a beam of light upon the water just in front of an amœba. It will be remembered that an amœba shows a negative tropism to light. When the amœba reached the beam, it reversed its movement, then moved forward again. Again it reached the light beam and

withdrew. After it had encountered the beam several times, it changed its direction and avoided the beam entirely. This experiment was carried on with five amœbas and was repeated with them a number of times at intervals of about three minutes. In later trials three of the amœbas made fewer forward movements before changing direction than they had first made. It is not understood how an animal like an amœba, which consists of only one cell, can modify its response in this way.

Learning begins with the inherited reactions. Since learning consists in modifying responses, the simplest learning must consist in modifying the inherited responses, that is, tropisms, reflexes, and instincts. The "learning" by the amœbas which has just been described is an example of a modified tropism. More striking examples of learning of a similar type have been observed with some of the simpler Metazoa, for example, starfish. Jennings trained a number of these animals each to use a certain arm in turning itself over when placed on its "back." One of the starfish learned this lesson after one hundred eighty trials distributed over a period of eighteen days. More astonishing still is the fact that a week later it used the same arm to turn itself over, though it had not in the meantime repeated the action. Somehow it retained, or "remembered," what it had learned.

The simple action of turning over is a reflex, just as is the contraction of a hydra when its tentacles are touched. But using one certain arm in turning over is clearly different from the inherited reflex. Ordinarily when the nerves on the "back" of a starfish feel the stimulus given by the contact of a rock, the impulse is carried by other nerves to muscles in any one of the arms which might be used in turning over. But after the starfish had been trained, the same stimuli on the nerves of the back were carried only to the muscles of a certain arm. The ordinary reflex had been modified by training.

A few examples of modified tropisms and reflexes of Metazoa even simpler than the starfish have been reported. Examples of modified reflexes and instincts are common with animals higher in the scale of life. One investigator trained crayfish to come to him for food. Another taught May-fly larvæ to come for food in the bright sunshine, although these animals instinctively avoid

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FIG. 257. Why are horses capable of learning more tricks than are fleas?

light. One of these May-fly larvæ, much "brighter" than the others, learned after two months of training to come quickly to the upper side of a rock and make for its feeding place when the rock was slightly jarred. Cockroaches were trained to distinguish between left and right. A carp, after being lifted out of the water on a barbless hook and then returned to it a number of times, learned not to eat worms which were on a fishhook, and to distinguish between such worms and those which were free. A carp ordinarily draws in water when it approaches its food, but this "trained" carp learned to do just the opposite. On approaching a worm it sent a current of water toward the worm. If the worm was free, the current lifted it somewhat, whereupon the carp ate it. But if the worm was on a hook, the current did not lift it, whereupon the carp made no effort to suck it in. Dogs, elephants, monkeys, and other mammals are able to change their inherited responses more than can animals farther down in the scale of life, because their brains are more complex (Fig. 257).

Learning involves a choice of response. When an organism reacts to an ordinary situation with its customary tropism, reflex, or instinct, it does not learn. No matter how often it might repeat such an action, it would not learn, because there is no choice of action. There was no stimulus to act in any but the usual way. If, however, some new condition is introduced, then it becomes

necessary for the animal to choose which action it will take. To illustrate, the amœba crawling into the beam of light could choose between continuing in the unpleasant light or going in some other direction where the unpleasant condition might not be encountered. The starfish placed on its back with all but one of its arms fastened down could choose between lying still in spite of the stimulus to turn over or using its one free arm. The crayfish seeing food held out to it could either follow its instinctive tendency to avoid a big moving object, even though by so doing it remained hungry, or it could approach the threatening object and get the food. With the simpler animals the choice is of course automatic and immediate. The animal does not consider or plan what it will do, as a man would. It reacts in the way which is easier or more satisfying at the moment.

Mrs. Joseph Watson

FIG. 258. Unique learned response. Can you suggest a method which might have been used in teaching the animals to perform this trick?

Learning depends largely upon pleasure and annoyance.[1] When an animal meets any unusual condition in its environment, it tends to react in accordance with some inherited tropism, reflex, or instinct. But if there is present some other condition, which pleases or annoys the animal, it may modify its ordinary response. It may need to perform many actions before it happens by chance to hit upon the one which brings satisfaction by securing the pleasure or reward or by avoiding or getting rid of the annoyance. Whenever the animal again meets the same situation, the tendency is to repeat the actions which before resulted in satisfaction and to eliminate those which brought annoyance or did not yield satisfaction. Finally a series of actions constituting a habit is formed. To illustrate these statements: The amœba crawling into a beam of light immediately reversed its direction. It again

[1] *Annoyance* (an noi′ance): that which displeases or annoys.

went forward and upon striking the light again retreated. It repeated the action until finally it succeeded in avoiding the unpleasant condition. The starfish placed upon its back was uncomfortable. It probably tried to use various arms before it chanced to use its one free arm and thus finally succeeded in turning over. The crayfish when offered food found hunger annoyance stronger than fear annoyance. In each of these and the other cases which have been cited, the animal secured satisfaction by performing an unusual action (Fig. 258). The result of this satisfaction was to cause the animal to repeat the action under the same circumstances later.

Simple learning is a trial-and-error process. It is clear that in its simplest forms such animal learning is merely the result of trial and error. The stimulus furnished the animal which is being trained is usually something pleasant, like food, or something unpleasant, like receiving an electric shock or being left alone. In seeking the pleasant and avoiding the unpleasant condition, the animal finally changes its original reactions and forms the habit of reacting in a certain unnatural way. But habits can thus be formed only provided the animal repeats the new reaction many times.

How animals learn by modifying their responses through trial and error is well illustrated by the actions of animals in learning to find their way through a labyrinth, or maze. Thorndike describes such an experiment with two chicks six to twelve days old. Using books for walls he constructed a simple maze connecting with the main pen and placed each of the chicks in turn in the space where the single chick is shown in Fig. 259. The chick reacted with aimless movements repeated many times, such as running about making loud cries and jumping at the walls. Finally it happened to find the way out of *C* and in the same way discovered one by one the various turns of the maze. After several aimless movements at each turn it found its way into the main pen with the rest of the chicks, where it was content to remain. When it was again put into the maze, it behaved much as before but took a somewhat shorter time to escape. With later trials it made fewer and fewer useless and aimless movements. Finally each chick learned to escape from *C* into the main pen within five or six seconds.

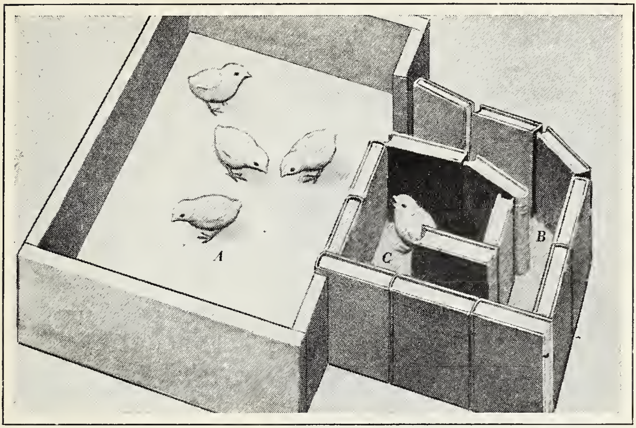


Fig. 259. An experiment in animal learning. How did this learning depend both upon trial and error and upon pleasure and annoyance?[1]

By a similar process of eliminating useless movements by trial and error a land snail learned a maze with one turning. Ants learned a maze with several turnings. Fish learned very simple mazes. A green frog took a hundred trials to learn a maze with only two choices, and a toad was about equally "stupid." Turtles, however, learned a maze with four blind passages and two sloping boards, one of which the turtles had to learn to ascend and the other to descend. The maze was further made complex by requiring the turtles to turn as soon as they reached the bottom of the descending board. They soon learned to begin to turn before they reached the bottom, and finally to drop over the edge of the board as soon as they reached the top.

Learning frequently involves habit formation. The tricks which dogs, cats, monkeys, and other animals learn are of course modified inherited responses. Through repeated trial and error, accompanied by rewards for the desired responses or punishments for the undesired ones, the animal acquires the habit of reacting in a certain way in a certain situation (Fig. 260).

[1] After Thorndike's *Educational Psychology*.

Occasionally there are reports of remarkably intelligent dogs or horses which apparently think and reason like people. A gifted Arabian horse, Muhammed of Elberfeld, Germany, was reported to have learned to add and subtract in two weeks; to have passed from multiplication and division to the use of fractions in three days; and later to have learned to solve problems in square root and cube root. Rolf, the Mannheim dog, was reported to be able to do similar things. But careful scientific observations of these animals convinced scientists that the animals were not really able to solve the problems they seemed to solve. Though it was not discovered just what were the stimuli which caused the animals to tap out with their feet the correct answers, there were a number of reasons which convinced the experimenters that these responses were after all only instinctive reactions modified through trial and error into habits, and that the animals reacted to signals given by somebody present.

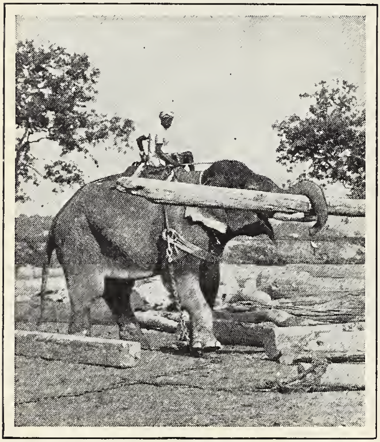


FIG. 260. An elephant can be taught to pile these heavy teak logs in neat piles. After he has established the necessary nerve connections, he will pile logs all day steadily and carefully, and needs nobody to direct him or to see that he keeps working. Many men under the same conditions would neglect the work or would not make neat piles if there were nobody to watch them. How do you account for the fact that in this case the elephant is more "trustworthy" than man?

Self-test on Problem XX-A. 1. *Unlearned* responses are gained only through experience.

2. *None* of the animals in the lower phyla are able to profit by experience.

3. It is *possible* to modify *two* of the three types of inherited response.

4. A starfish placed on its back and allowed to turn over by using any of its arms learns *little.*

5. When an animal repeats an action in the same way a number of times a _ _(?)_ _ is formed.

6. The simplest animals do *little* planning, but merely try one possible response after another until they happen upon the one which satisfies the stimulus.

7. In general one would expect a fish to acquire a habit *less* quickly than a crayfish.

8. *Some* mammals other than man are believed by scientists to be able to solve difficult problems in arithmetic.

Problem XX–B · What are Some Characteristics of Higher Learning?

Higher learning involves memory ideas. Some animals seem capable of reactions which require more "intelligence" than modified reflexes and instincts. Some of the higher monkeys seem able to use memory ideas of a high order. For instance, one investigator threw a piece of apple, and, while a monkey was picking it up, he threw other pieces in different directions. After eating the first piece, the monkey secured the second and sat down to eat it. When he had finished it, he went for the third piece, which he ate likewise. He then paused to watch a flying bird and to scratch himself before starting after the fourth piece. This he found where it had rolled under a board. After he had eaten this, he again sat down.

Human learning. The brain of man is much more complex than that of any of the other animals. Man's cerebrum is twice as large as that of the highest monkeys. The cerebrum is made up of two great hemispheres composed each of approximately eleven billions of neurons. The outer surface of the cerebrum consists of gray matter composed chiefly of the cell bodies of neurons. The interior of the cerebrum is white matter consisting of bands and bundles of nerve fibers. These connect the various areas of the brain with the other parts of the nervous system (Fig. 261). The vast number of nerve cells which make up the human brain make possible thinking, planning, remembering,

reasoning, and the other higher thought processes. These higher thought processes distinguish man from all the other animals.

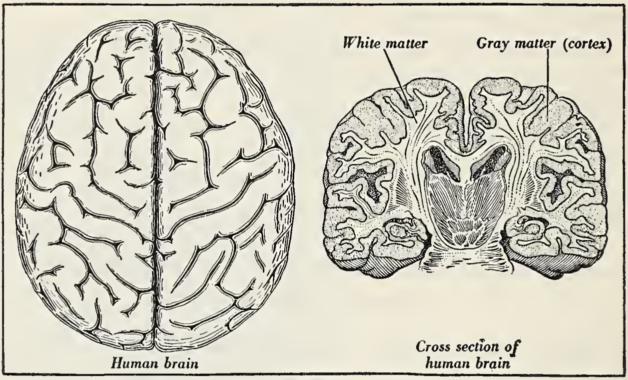


FIG. 261. *A*, human brain, seen from the top, showing both hemispheres; *B*, section through cerebrum, showing gray matter of cortex and white matter. What is the advantage of having the convolutions, or folds?

The higher centers of the brain may be compared "to the captain of a steamer who issues orders to the man running the engine when to start and when to stop, and who has his hand on the wheel so as to guide the course of the vessel."

Habit-forming in man. Man, like many of the other animals, forms habits without thought by repeating certain actions in the same way until the nerve patterns are fixed. But man is also capable of learning habits purposefully.[1] This an animal cannot do. If it changes its reactions at all, it does so by trial-and-error learning. The difference between the learning of animals and that of man in this respect can be illustrated by the learning of some skill such as swimming. A puppy or a baby duck does not need to be taught to swim, but all dogs swim like other dogs and all ducks swim like other ducks. It would be very difficult or impossible to teach them to use any other sort of swimming stroke than the one they are instinctively able to use. A child, however,

[1] *Purposefully* (pur′pus ful y): with plan or purpose.

does not, like the dog or duck, swim instinctively. He must learn, and usually it is not easy for him to do so. After many trials, which usually run over a considerable period, he learns first to keep his nose above water and to swim a short distance. He requires much more practice before he learns to swim easily.

The acquiring of a skill such as swimming is accomplished in this way: Lacking a ready-made instinctive response, the boy must learn an effective way of responding. He must therefore use the higher levels of his brain at the start. He watches other boys swimming, notices what they do, asks them how to use his arms and how to kick, and remembers what he has been told or has read about swimming. When he first enters the water, he has a fairly clear idea of what he wants to do. He directs with the nerves of the cerebrum every action he performs. The impulse travels from the higher brain centers along the nerves to the muscles he wants to use. He notes which movements give desired results, repeats them again and again, and at the same time consciously tries to eliminate those which his own experience and the advice he receives convince him do not give the results he wants. Finally the desired habit is formed, and the stimulus of the water sets up the response without the necessity for thought any longer. The higher centers of the brain are no longer concerned, and the action of swimming is entirely controlled by the lower centers.

How human beings change a habit. If later the boy wishes to change his style of swimming to some better method, he must proceed much as before. Using the higher centers of his brain, he carefully studies the differences between the movements he has been making and the new ones he wishes to make. He consciously changes his movements in the water, commanding the muscles with the upper brain centers. After long practice he learns to make the new response. When the new movements have become automatic, the higher brain centers are no longer needed. The activities are controlled by the lower centers.

***Rules of habit formation.** Man is the only animal possessing a sufficiently complex brain to enable him to change his habits at will. The rules for forming desirable habits and breaking up undesirable ones are definitely known and are fairly simple (Fig. 262). Suppose you have formed the habit of taking too much

time in starting to do your studying or your work at home. First, you must decide that you want to break this habit. You must analyze the actions you now perform which take too long or which prevent your getting to work at once. When you have decided what new acts you want to perform and what old ones you want to eliminate, you begin your work vigorously, being careful to perform the acts you have planned and to leave out all that do not help. Whenever you have such tasks to perform, you follow your new plan without any exceptions. Before long you will have formed the new habit. You will then do your work without thinking much about the way in which you do it. In other words, the higher centers of the cerebrum will no longer be concerned with carrying out the new actions. The lower brain centers will take care of the habit automatically. If, however, during the formation of the habit you permit yourself to go back to the old habit of wasting time, the new habit will require much longer to establish. If you permit too frequent exceptions to the actions necessary in establishing the new habit, you will not succeed in forming it at all.

Fig. 262. Can you state some of the steps necessary in learning to play golf?

Continued learning. In the learning experiment with starfish described in an earlier part of this chapter, the biologist Jennings found that young starfish acquired the modified reflex more readily than did older specimens. Animal-trainers usually use young animals rather than old ones. Children often gain skill in games and other muscular activities more readily than do grown people. From observations such as these the old saying "You can't teach an old dog new tricks" has come to be widely accepted as applying

to all sorts of learning. It is often true that older people have more difficulty than children in learning to perform such muscular activities as those involved in playing the piano or in playing tennis. The greater difficulty, however, is probably not due to its being harder for them to learn but rather to changes in their bodies, or to the fact that usually they do not practice so faithfully or try so hard.

Whether one learns to play a game expertly or to perform intellectual tasks well depends largely upon how strongly one wants to succeed. "Old dogs" usually learn less easily than "young dogs" probably because they have less abundant energy; because they have undergone changes in bone and muscle; because they have no real desire to learn that particular skill; and possibly because they already have acquired habits which interfere with the new learning and which are difficult to break. Many experiments have shown that it is not true that children gain intellectual knowledge more rapidly than do older people. The contrary may even be the case. We gain new knowledge which involves the higher nerve centers of the cerebrum, such as learning to read a new language or to use higher mathematics, most easily in the early twenties. But there is so slight a loss of mental vigor as one gets older that, if one remains well and normal, there is no time of life when one cannot undertake new intellectual tasks with success.

Individual differences. If you have observed animals, you have no doubt noticed that some seem more intelligent than others. Jennings found that some of his starfish learned to turn over with one certain arm more readily than did others. In nature those animals of any kind which are the more "intelligent" — that is, the more able to learn quickly and effectively — are the ones most likely to grow to maturity and have offspring. Hence under natural conditions the "stupider" ones are likely to be eliminated by enemies, while the "brightest" and therefore the "fittest" are likely to survive.

Many people think that a person who is superior in one respect is likely to be very inferior in other respects. The opposite is the case. Though there are exceptions, it is in general true that the person who can do one sort of intellectual task well is likely also to be able to do other sorts of intellectual tasks well.

Advantages of a long infancy. The human baby is under its parents' care and instruction for a longer time than is the young of any other animal. The length of infancy in general bears a close relation to the complexity of the nervous system, especially to the degree to which the cerebrum is developed. Thus few invertebrates, even the highest ones, the insects, are cared for by their parents. Few even of the lower vertebrates, the fish, amphibians, and reptiles, have a period of infancy during which their parents provide them with food, shelter, and protection. The birds do for the most part take care of their young for a short time, and the mammals for a longer time (Fig. 263). The highest monkeys, which are the animals with the most highly developed brains next to man, have a period of infancy which lasts sometimes for several years. Man, with the most highly developed cerebrum of all animals, defines the period of dependence legally as lasting twenty-one years, or until the young man "comes of age."

Newton H. Hartman

FIG. 263. What evidence of parental care is shown in this picture of the mother and young llama in the Philadelphia zoo? Can you determine from the characteristics shown in this picture the order of mammals to which the llama belongs?

The more highly developed brain makes a period of infancy necessary for the survival of the species. The higher animals, with their complex nervous systems, must have time to make and perfect the responses necessary for their existence. The more complex the cerebrum, the greater the possibilities for varied behavior, and the longer the time that must be allowed the animal in which to learn and perfect the desired responses.

At birth the human baby with its billions of cells in its cerebrum is more helpless and more in need of parental care than any other

animal. At the same time it is more capable of learning than any other animal. During its years of infancy, therefore, it is gaining, in ways not yet known, a body of experience which affects its later behavior. The broader and richer the experiences which the growing child has, the greater is the number of impressions retained, and hence the greater the possibilities later for rich thinking, remembering, and planning. How much a human being might learn is not known. Probably there are no limits to human learning. It is certain that nobody has ever developed more than a small fraction of the possibilities of which his brain is capable.

Self-test on Problem XX–B. **1.** Scientists believe that *no* animals below man are able to use memory ideas.

2. The complex thinking which man can do is made possible by his possession of a complex __(?)__.

3. *Few* animals lower in the scale of life than man can form or change habits purposefully.

4. After a man has formed a habit, the habit is controlled by the *higher* centers of his *brain.*

5. It is *difficult* to change a habit unless one wants to change it.

6. Adults can gain intellectual knowledge *as* readily *as* children.

7. *Few* older people can learn, *though* they wish strongly to do so.

8. A student who is "*good*" in his school work is very likely to be "*poor*" in most other kinds of learning.

9. In general the *less* complex the brain of an animal, the *longer* must be the period of infancy.

10. Probably the most intelligent of the animals other than man are (1) horses; (2) elephants; (3) dogs; (4) higher monkeys; (5) pigs; (6) cats; (7) chickens.

Self-test on Biological Principles. What illustrations can you give from this and the preceding chapter which seem to prove the principle "A reaction is successful if it aids an organism directly or indirectly to secure or to conserve energy"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** Do the examples of trial-and-error learning given on pages 394–395 seem in general to prove the statement "The higher in the scale of life an animal is, the more complex a maze it can learn"? Are there exceptions? Explain.

2. Explain how pleasure or annoyance aided the carp in learning to avoid a worm on a hook.

3. Why does a baby have to learn to walk?

4. What possible advantages over other animals has man derived from his erect posture?

5. State the seven factors involved in learning which are given as headings of sections under the first problem in this chapter. Illustrate each by means of the statements concerning the meadow larks in the first paragraph or by some observation of your own.

6. Can you explain step by step how one learns to drive an automobile?

7. Why is it true that man can learn as long as he lives, while dogs and other mammals can learn little after they have matured?

8. Suppose a person is inclined to lose his temper at the least provocation and to say things for which he is later sorry. What are the steps which he can use to break this bad habit?

9. In studying animal behavior investigators frequently use a "puzzle box"; that is, a box from which an animal can escape only by performing some special act such as pulling a string, pushing against a certain spot, raising a latch, and the like. Thorndike first allowed a cat to learn how to get out of a certain puzzle box. He then put into the box another cat, which watched the first one escape. But the second cat was unable to learn from observing the first cat how to get out, though it watched the escape many times. Thorndike also had monkeys watch him open a box to see whether they could then open it by imitation, but almost without exception they could not. Can you explain these facts on the basis of the development of the cat's and the monkey's nervous systems?

Exercise on Scientific Method. 1. Recognizing Defects and Errors in Conditions. Most people enjoy watching the behavior of animals and later telling what they have observed. They are likely to tell also what the animals thought or why they acted in the way they did. How much of such statements is likely to be scientific evidence? How much is practically certain not to be? Explain.

2. Making Inferences and Planning Experiments. A certain investigator carried on a learning experiment with a normal man, a defective man, six boys of varying ages, one defective boy, five monkeys, sixteen dogs, seven cats, and a horse. In this experiment the horse proved "stupider" than any of the other subjects. What conclusions might one draw from these facts? How would you go about testing these conclusions to find which was correct?

Exercise on Scientific Attitudes. Some people, called phrenologists, claim that they can tell one's character by the "bumps" on one's head and sometimes even claim to be able to tell from one's "bumps" the "past, present, and future." Are such claims scientific? (Look up phrenology in an encyclopedia or in a textbook of psychology.) What scientific attitudes should one possess in considering the claims of phrenologists?

Project 20. To make a maze or a puzzle box and find how long it takes an animal to learn the maze or the box. Make a maze with a few turns and with a few choices of passages or make a simple puzzle box the door of which opens only when a string is pulled or when an animal pushes against one certain spot. Put some food at the outside door of the maze or just outside the puzzle box. Put into the maze or the box a cat, a white rat, a chick, or some other animal. Time it to see how long it takes to escape. Watch what sorts of movements it makes before it finally finds its way out. Allow it to eat some of the food; then repeat the experiment. Repeat the experiment several times a day until the animal has learned to escape with few or no false movements.

Consult some textbook on animal psychology if one is at hand to find out about the Hampton Court maze or other mazes and puzzle boxes which have been used in similar experiments in animal learning.

Chapter XXI · The Special Sense Organs

Questions this Chapter Answers

Does man possess only five kinds of sense organs?

What is the nature of the senses in various animals?

What are the structures and functions of the human sense organs?

What is the importance of the senses in survival?

Fig. 264. Sensitive plant before and after being touched. Self-test on Biological Principles: To what extent may such behavior possess survival value for the plant?[1]

Problem XXI–A · What is the Nature of the Senses of Touch, Taste, and Smell?

Many sense organs. We are accustomed to think of the special senses as being five in number. The lower organisms have fewer than five senses, while the highest organism, man, has more than twice that many. The more familiar special sense organs of man include those for sight, hearing, taste, smell, touch (or pressure), heat, cold, pain, equilibrium,[2] and the sense of muscular effort (kinesthetic sense).

[1] From Eikenberry and Waldron's *Educational Biology.*

[2] *Equilibrium* (e kwi lib′ri um): having to do with balance, or keeping right side up.

The senses depending on contact. The sense of touch, or pressure, is the most primitive of all the special senses. All the animals and even some of the plants possess this sense, though the one-celled animals, and the plants that possess this sense, have no special organs of touch such as nerves. The leaves of the sensitive plant fold together rather quickly when anything comes in contact with them (Fig. 264). Since, so far as scientists know, plants do not have nerves, it is thought that the contact in some way causes water to be withdrawn from certain cells near the bases of the leaves. Then as these cells collapse, the leaves droop for lack of support.

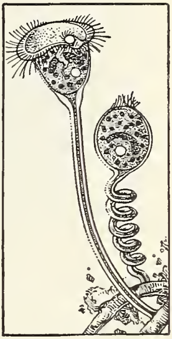


Fig. 265. The vorticella at the left is feeding. Can you suggest what has just happened to cause the vorticella at the right to assume the shape it has?

Many of the Protozoa have certain parts of their one-celled bodies which are specially sensitive to touch (Fig. 265). With *Paramecium* it is the hairlike projections (cilia) and with *Euglena* (see Index) it is the whiplike projection (flagellum) that are sensitive.

In the simpler Metazoa special nerve endings in the skin which are distributed over the entire bodies of the animals serve as organs of touch. That these touch organs are of more than one kind, even in fairly simple animals, seems evident from the fact that they are sensitive not only to contact but also to heat and to pain. The antennæ of animals like crayfish and insects are especially sensitive to touch.

In the higher animals there are four different kinds of nerves in the skin which respond to contact.

Experiment 78. Are there different nerve endings in the skin for the senses of pressure, pain, heat, and cold? On the skin of your forearm mark a small square in ink. Make a similar square on a sheet of paper. Secure a small wire hairpin or a small nail with a smooth point. Holding the nail in the other hand, run it lightly and not too rapidly back and forth over the skin marked by the square. Do you sometimes touch a spot which seems very sensitive? This spot is probably an ending of a nerve of pain. Put a dot on the record square in the cor-

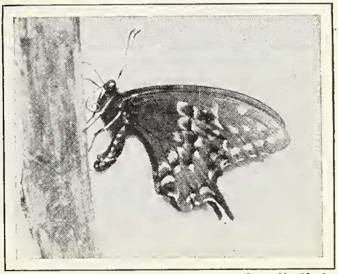
responding spot. Heat the nail slightly, so that it is definitely warm. Pass it over the skin in the same way. Do you find spots especially sensitive to heat? Mark these with small circles on your record square. Cool the nail and try to find the "cold spots." Mark these with small crosses. Do you find any spots which feel hot when touched with the cold object? Do you find any spots where you merely feel the nail without its causing sensations of heat, cold, or pain? If so, record the location of such spots with a cross inside a circle. Complete your record and put a legend below it which answers the question of the problem.

Experiment 79. Are the nerve endings of touch closer together in some parts of the body than in others? Two individuals will need to work together to try this experiment. Take two pins and holding them about one fourth of an inch apart touch the points lightly but firmly to the back of your partner's hand. Can he feel two separate points? Now move the pins closer together. Can he still feel two points? Occasionally use only one pin, to be sure he is not imagining that he can distinguish the points. How close together do the nerve endings of touch seem to be on the back of the hand? Try the same experiment on the tip of a finger, the tongue, the shoulder, the forehead, and other parts of the body. Where are the nerve endings closest together on the parts touched? Where farthest apart?

The senses of taste and smell. These senses are considered as chemical senses since they depend on chemical reactions between the substances which are tasted or smelled and the organs which detect them. For the animals which live in water, and this list would include most of the animals simpler than the insects, the senses of taste and smell are believed to be practically the same. They are useful to these animals chiefly in securing food. With the lower organisms, moreover, the sense of touch is closely associated with smell. With many of the lowest forms it is not yet known whether the recognition of food is due to a mechanical sense of touch or a chemical sense of taste and smell.

Results of several experiments indicate that earthworms have a sense of taste and perhaps also of smell which is distinct from the sense of touch. Thus, if placed on filter paper which is moistened with pure water, the earthworms will not burrow. But if the filter paper is moistened with water from the ground in which they live, they will burrow at once. Further evidence of a sense of taste is furnished by the fact that the earthworm prefers lettuce

and cabbage to other kinds of food. Very small sense organs on the surface of the body, especially near the head end, may account for these reactions. It is believed by one investigator that a certain land snail has its sense of smell in the ends of its horns and its sense of taste chiefly around its lips. The mouth parts and perhaps also the antennæ of the crayfish serve as organs of taste and smell. In still water the crayfish is not guided to food by its senses of taste and smell; but in running water it will move against the current, upstream, considerable distances and will find food from the taste or the smell of it in the water.

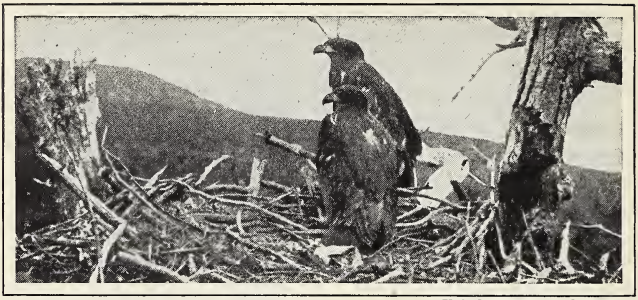


Cornelia Clarke

FIG. 266. Some butterflies taste with their feet. Self-test on Scientific Method (Making Inferences): Can you suggest any advantages which the butterfly may derive from this adaptation?

Many insects have a distinct sense of smell, located, it is believed, in the antennæ (Fig. 266). Bees are thought to be able to distinguish certain substances more readily than we can and to be better able to analyze odors, that is, to distinguish between two or more odors at the same time. The sense of smell has been observed to play an important part in the mating habits of many insects, such as moths. The male moth is believed to detect the presence of the female by the sense of smell. Ants are believed to be able to distinguish between a considerable number of different odors.

The taste and smell senses of vertebrates. The senses of the lowest chordates are believed to be more like those of the earthworm than like those of the higher vertebrates or even of the highest invertebrates. Fish, however, are able to taste and smell to some extent, as is shown by the fact that if similar samples of food, and of other substances which are not edible, are put into the water, the fish will choose the food. It is believed by some observers that salmon and other fish which live in the ocean but which come to fresh water to spawn are guided to the spawning grounds by the sense of taste, that is, by the differences in the degree of saltiness of the water.



U. S. Department of the Interior

FIG. 267. Young bald-headed eagles (Acadia National Park, Maine). The eagle is a bird of prey. Which of its senses should you expect it to depend upon chiefly in locating food? Justify your answer

Very little is yet known about the senses of taste and smell in the frog, though other amphibians — for example, some of the newts and salamanders — are able to locate food by these senses. Of the reptiles, turtles have been observed to distinguish between various sorts of food, both when they are in and when they are out of the water.

Birds have a sense of taste and of smell; but these are probably not very keen, since the bird depends chiefly on sight and hearing for locating food and detecting enemies (Fig. 267). Some young chicks indicated that they possessed a sense of taste by "showing disgust" when they picked up orange peel instead of egg yolk. One investigator who studied twenty-seven of the thirty-five existing orders of birds came to the conclusion that in general the higher the order of bird, the less keen its sense of smell.

Most of the mammals have a very keen sense of smell. Wild animals depend on this sense chiefly to warn them of enemies and to tell them of the presence of their prey. Many of the mammals, the dogs especially, have a much keener sense of smell than man.

* **The organs of smell and taste in man.** A spot in each of the upper nostrils about the size of a dime contains the nerve endings which give man his sense of smell. Each of these special nerve cells has six or eight hairs (cilia) upon the exposed end. It is believed that molecules or exceedingly small particles are carried to

these nerve cells in the form of gases, and that these particles produce chemical reactions in these nerve cells. The nerves of smell, however, soon lose their ability to respond to a particular odor to which they are constantly exposed. For example, when a person first enters a badly ventilated room, he is conscious of many disagreeable odors. But if he remains for even a few minutes, his nerves of smell no longer respond to those odors, and he does not notice that the air is foul.

*The nerves of taste end in small buds (papillæ) on the surface of the tongue and also to some extent on the roof of the mouth and on the walls of the throat. Only foods which will dissolve can be tasted, for the nerve endings are in little pits which only liquid can reach. All other so-called tastes or flavors are really odors. This fact explains why foods lose flavor when one has a cold, for then the passages of the nose become so swollen and inflamed that air currents cannot bring food molecules to the nerves of smell.

Experiment 80. Can one distinguish such foods as onion, apple, and potato by taste alone? Blindfold a member of the class and have him hold his nose tightly. Then place upon his tongue a small piece of apple, onion, or potato. Can he tell which it is? You can use any substances that do not have a conspicuous salty, sweet, sour, or bitter taste and that are enough alike in texture so that one cannot feel the difference. Try the same experiment with maple sirup, cane-sugar sirup, and sugar sirup flavored with vanilla extract. Is it the difference in taste or in smell that allows us to distinguish such things?

Self-test on Problem XXI–A. **1.** Name eight special senses of man.

2. More organisms possess the sense of *sight* than possess any of the other senses.

3. Name four different kinds of sense organs which man possesses but which the Protozoa and sponges do not.

4. The chemical senses are those of *touch* and *taste.*

5. Certain *arthropods* are believed to have keener senses of smell than man.

6. Not *all* the chordates have keener senses than *all* the invertebrates.

7. Man's sense of taste is located *entirely* on the tongue.

8. Many flavors which we think are due to taste are really due to __(?)__.

Problem XXI-B · What is the Nature of the Sense of Sight in Various Animals?

The sense of sight. We have learned that nearly all plants and animals seem sensitive to light. Many of the lower animals, even

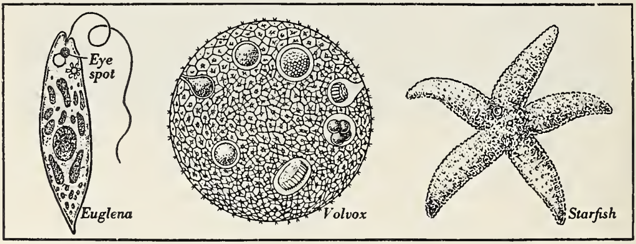


FIG. 268. Animals with eyespots. Each cell in *Volvox* has an eyespot. The starfish has an eyepit or eyespot at the end of each arm. To which phylum does each of these three animals belong?

a few of the Protozoa, have pigment spots which seem more sensitive to light than other parts of the body and therefore are called eyespots (Fig. 268). But we cannot say that these animals really see; for the eyespots are not really eyes, though those of some of the lower Metazoa are fairly complex in structure. Animals with eyespots probably see no more than changes between light and shadow. An earthworm has no eyespot, but instead has in its skin a large number of special nerve ends which are sensitive to light.

No true eyes are found in animals of the lower phyla. The only animals with true eyes are some of the higher mollusks, the arthropods, and the vertebrates. These eyes are of three sorts: (1) the simple eyes (ocelli) of insects and spiders; (2) the compound eyes of insects and crustaceans; (3) the lens type of eye as in vertebrates.

A simple eye consists of a bit of bulging, thickened cuticle[1] which acts as a lens in bringing light rays to a focus on the retina, or sensitive nerve ends, which lie beneath (Fig. 269). Nerves from the retina pass to the brain.

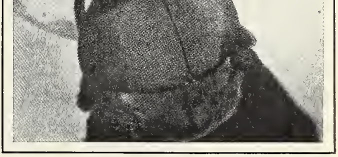
[1] *Cuticle* (ku'ti k'l): the outer covering of the body; the skin.

Cornelia Clarke

Fig. 269. Hunting spider guarding her egg case. The spider has simple eyes. Are there always six eyes, and are they always arranged as are those of this spider? Find the answer to this question by examining with a lens or reading glass the heads of various spiders

Simple eyes are more effective organs than the more primitive eyespots. Yet it is not yet definitely known how effective simple eyes are. There is considerable evidence which is believed to show that the animals with simple eyes can distinguish only general size and movement and can judge short distances.

Compound eyes, such as those of most insects, are essentially a large number of simple eyes closely crowded together (Fig. 270). Each one acts independently in focusing light rays. The result is an image many times repeated.



Lynwood M. Chace

Fig. 270. Compare these compound eyes of the horsefly with your own eyes

The compound eye is believed to be useful chiefly in

FIG. 271. The octopus and its close relative, the cuttlefish, have each two highly developed eyes. What phyla are there between the one to which the cuttlefish belongs and the chordates?

locating the direction of light and in detecting moving objects. Investigators are not agreed on whether the compound eye gives a fairly clear image or only general size and movement. Some investigators believe that with insects, like the grasshopper, which have both simple and compound eyes one form may be used for seeing objects near the insect and the other for seeing objects farther away. Others believe that the simple eyes serve to detect sudden changes in the intensity of light. There is considerable evidence which seems to show that invertebrates in general are color blind.

The lowest of the chordates have far more primitive organs of vision than many other animals lower in the scale of life (Fig. 271). Certain chordates (for example, the amphioxus (Fig. 131, p. 208)) have simple eyespots. All the vertebrates, however, have the lens type of eye, like that of man. This eye acts in such a way that a single image is clearly formed, much as a picture is taken by a camera.

Every vertebrate has two eyes only. Almost without exception fish, amphibians, reptiles, and birds have one eye on each side of the head. This arrangement is of value in permitting the animals to see more of their surroundings at one time. The higher mammals, including man, have their eyes placed more closely together on the front of the head. Such animals cannot see behind them, but they are better able to judge distances than animals with eyes farther apart.

Experiment 81.[1] What is the inside of an eye like? Secure from your butcher two or three fresh eyes from cows or pigs. With sharp-pointed scissors cut off the lids so that you have only the eyeball. Note the optic nerve at the back. Insert the point of the scissors into the back of the eyeball just above the optic nerve. Is the outer coat of the eye easily pierced? Is there any advantage in having the outside coat of the eye like this? Cut out the optic nerve to make a small opening in the back of the eyeball. Try to keep the jellylike liquid inside the eyeball from escaping. Now hold the eyeball so that you can look toward the front of the eye through the opening you have cut. By moving your head slightly you will be able to see through the eye the image of objects in front of the eyeball. This image you see is the same sort of image which the cow or the pig saw with the eye. Is it right side up or upside down? Make the opening in the back of the eyeball larger and allow some of the liquid to escape. Is it transparent? Examine the inside coating at the back of the eye. This is the retina. Carefully remove the jellylike liquid until you discover the lens. What is its shape? Examine the front of this lens for the iris, which you will find as a dark-colored coating over part of the lens, but with a round opening in the middle. This round opening is the pupil. In front of the iris is a watery liquid.

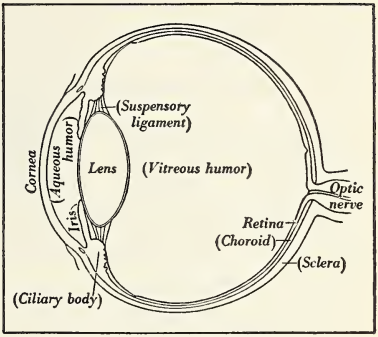


FIG. 272. The human eye. Can you state the function of each of the labeled structures?

***How we see.** Light enters the eye through the pupil, which is an opening in the iris (Fig. 272). The iris, the colored part of the eye, is made up largely of muscles, which regulate the size of the pupil. When the light is very bright, the muscles contract, making the pupil small. When the light is dim, the muscles relax, permitting as much light as possible to enter the eye. Just behind the pupil is the lens, which brings the light rays to a focus. The

[1] From *Introduction to Science* (Ginn and Company, Boston), by Otis W. Caldwell and Francis D. Curtis.

lens is elastic and is governed by small muscles. It is thinner when objects are far away and thicker when objects are near, and thus keeps the image focused on the retina. In the retina are found the nerve endings of the optic nerve. These are affected when light rays are focused upon them. The nerves transmit the stimulus to the brain, which interprets it as sight.

Self-test on Problem XXI–B. 1. We should not expect to find true eyes in animals lower than (1) Porifera; (2) Protozoa; (3) annelids; (4) mollusks; (5) chordates; (6) cœlenterates.

2. Arrange the following sight organs in order from most effective to least effective: (1) lens type of eye; (2) eyespot; (3) compound eye; (4) simple eye; (5) nerve endings sensitive to light.

3. Every vertebrate has __(?)__ eyes.

4. It would be *difficult* to see, even with perfect eyes, if the nerves connecting the eyes with the brain were destroyed.

Problem XXI–C · What is the Nature of the Senses of Hearing and Balance?

The sense of hearing. Darwin allowed earthworms to make their burrows in flowerpots, so that they could be carried from place to place. He found that if the pots were placed near a piano, the worms made no response whatever when music was played, but that if the pots were placed upon the piano, the worms drew back into their burrows at once when a note was struck. This experiment indicates that the worms did not hear but that they responded to the jarring caused by the vibrations of the piano wires, which were carried through the piano case to the flowerpot. The sensation was, so far as we know, received by the entire body and was more closely related to touch than to hearing.

This and other experiments have convinced experimenters that most animals are sensitive to vibrations in the air, the water, or the soil which surrounds them. There are no experiments, however, which have proved that any animal which is lower in the scale of life than the insect really hears.

The hearing structures vary considerably with different animals. The finely branched antennæ of gnats, mosquitoes, and

other insects are supposed to serve as hearing organs. Certain organs on the abdomen of the grasshopper (Fig. 273) and on the front legs of crickets are supposed to serve the same purpose. Such an organ consists of a tightly stretched membrane (tympanic membrane) which is thought to vibrate when sound waves strike it. In the pit beneath the membrane are nerve endings which pick up the vibrations and carry the sensation to the brain.

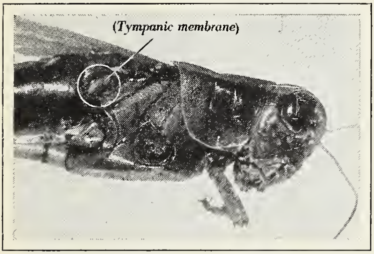


FIG. 273. Hearing organ of the grasshopper. To what part of the human ear does this membrane correspond?

***How we hear.** As the sound waves which are gathered up by the outer ear strike against the human ear drum, they cause it to vibrate. The vibrations are carried across the middle ear by the successive movements of three tiny bones. The third of these bones fits closely against the thin membrane which separates the inner ear from the middle ear. As the bone vibrates, it causes movement in the fluid which fills the inner ear (cochlea). These waves stimulate the endings of the nerves which line the inner ear. The impulses are then carried to the brain and are interpreted as sounds.

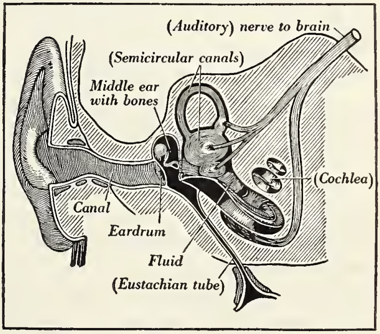


FIG. 274. Using this diagram, can you explain how we hear?

All vertebrates possess inner ears very similar to those of man (Fig. 274), though all do not have the special ear parts that make hearing possible. As with other structures, the ears of vertebrates

James's Press Agency, London

FIG. 275. Hindu snake-charmers. Exercise on Scientific Attitudes: Does the evidence in this picture seem to agree with or to contradict that secured by the investigator of hearing in rattlesnakes? Which of the scientific attitudes (pp. 12–13) should one possess in considering this evidence on the hearing of snakes?

become in general more complex the higher the animal is in the scale of life. Fish and snakes possess only the inner ear. Sound waves can reach this ear, therefore, only through the bones of the head. The frog has an ear drum on the surface of its body and inner ear parts much like those of man. The ear of a bird is much like the ear of a mammal, except that the hearing part of the organ is less perfectly developed.

Fish are believed to hear the sounds which are made under water. Experiments with frogs, mud puppies, and other amphibians seem to indicate that these animals also can hear. Experiments with reptiles, however, indicate that some are able to hear and others are not. For example, one experimenter found that a certain lizard when not disturbed closed its eyes and opened them again at intervals of about half a minute. He therefore waited until the lizard had closed its eyes, and after about ten seconds he blew a note of a whistle. The lizard immediately opened its eyes. The experimenter repeated this investigation with the same lizard and with lizards of another class, using different tones. The results were always the same. From these

experiments he concluded that these lizards at least could hear. Another scientist, experimenting with rattlesnakes, and a third with turtles, found no evidence to indicate that either of these reptiles can hear (Fig. 275).

Scientists are not agreed with respect to the range of sounds which man can hear. The range of sounds is variously estimated at from about twenty vibrations per second to about thirty thousand vibrations per second. He cannot hear deeper or shriller sounds than these. Birds and mammals have a considerable range of sounds which they can hear. Some insects are believed to be able to hear sounds shriller than man can distinguish. Other animals are believed to be able to hear deep tones to which man is deaf.

Experiment 82. What are some of the individual differences in hearing among your classmates? Blindfold a member of your class; then have him close one ear while you bring a vibrating tuning fork slowly toward the other. Have him tell you when he first hears the fork. Measure with a ruler the distance of the fork from his ear. Then repeat the experiment with his other ear. Repeat the experiment with other members of the class. Are both ears of most of the boys and girls equally acute? Is there a wide or a narrow range of difference in the distances at which different members of your class can hear the sound? If you have a pet, such as a dog or cat at home, try the same experiment on it and compare the results with the others.

Exercise on scientific method (evaluating data and inventing experiments). What reasons can you think of which might cause you to doubt the accuracy of your results? Is any check experiment needed in order that you may be reasonably sure that your results are correct? Why? If so, what sort of experiment would you perform?

The sense of balance. Most animals tend to remain right side up. With the plants and the lower animals the righting action is the result of one or more tropisms. It is not known what causes most of the animals to keep right side up. It is believed that some of the lower animals remain upright because the lower portions of their bodies are composed of heavier particles. Crustaceans, such as crayfish and lobsters, have an organ of equilibrium, or balance (called a statocyst), on the first joint of each of the small antennæ. This organ consists of a pit lined with sensitive hairs and inclosing one or more tiny grains of sand. As the animal changes position the grains of sand float about in the organ and

touch new sets of nerves. Thus the animal becomes aware of changes in position and can keep itself in balance. One experimenter observed that the crayfish itself places the sand grains in the balancing organ. When the exoskeleton is shed, the lining of the balancing organ is shed, too. The experimenter placed a newly molted crayfish in a tank in which there were no solid particles except iron filings. That it used these in place of sand was proved by the fact that a magnet would attract the head.

Insects and spiders have no organ of balance corresponding to that of crustaceans. Their ability to keep right side up may possibly be due to reaction to light or to the action of gravity owing to the way in which their body materials are arranged.

In all vertebrates the organ of balance is located in the ear, though the sense of vision too may be of great help in maintaining equilibrium. Evidence supporting this statement is found in the fact that aviators in coming out of cloud banks sometimes discover that they have been flying upside down without knowing that they have been doing so. In man and other vertebrates the organ of balance is part of the inner ear. This structure consists of three tubes, called semicircular canals, which are placed at right angles to one another. These canals are filled with a liquid, and their walls contain very sensitive nerve endings. When the head is moved, the position of the fluid is changed, and a different set of nerves is affected. Thus the brain learns of the general position of the body and can keep it in equilibrium.

Survival values of the senses. The senses are necessary for the survival of animals. An unusual contact may reveal an enemy the presence of which might not otherwise be discovered. If, therefore, an animal is suddenly touched, it is likely to flee, to get ready to fight, to contract, to roll up in a ball, to play dead, or to react in any one of a number of other ways, depending on the animal. But whatever reaction the animal makes is to aid in protecting it. Similarly, with the senses of heat and cold the organisms which possess these senses are guided to an environment which possesses the temperature conditions best suited to their successful living. They are warned in time to escape if the temperature conditions are changing to an extent which might prove harmful to them. The sense of pain also aids animals in avoiding

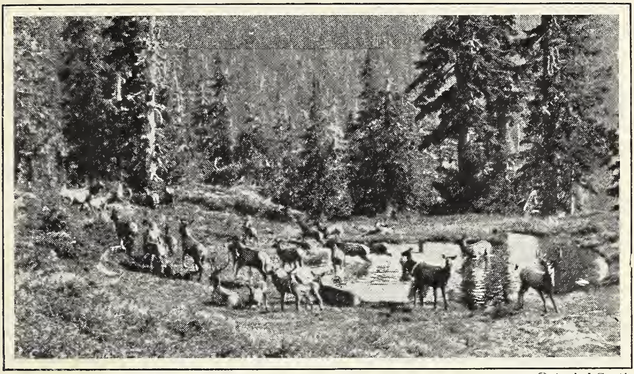


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FIG. 276. Elk near Standing Creek, Washington. What evidence is there in this picture that elk depend on keen eyesight and hearing as aids to survival?

conditions which might prove harmful. This sense in a certain respect acts as a check upon the senses of touch, heat, and cold. Thus, the sense of pain warns the animal when the contact is too violent or when the heat or cold becomes too intense. If the pain caused by a certain experience is sufficiently great, the animal is not likely to repeat the experience. Keen eyesight, hearing, taste, and smell likewise give warning of unfavorable conditions and guide the animal to food or other necessities of life (Fig. 276). The sense of equilibrium enables the animal to keep in the bodily position which helps it best to live successfully.

As was stated in the preceding chapter, organisms differ more or less in every respect from every other organism of the same kind. Some animals must therefore inherit much keener senses than some other animals of the same kind. An animal which lacks any of the senses necessary to its successful life in the environment in which it lives is less likely to grow to maturity and to have offspring than an animal which is better equipped with these senses. Under natural conditions, therefore, only those animals which are better equipped than others of their kind are likely to grow to maturity and have offspring. Hence there is always in nature a survival of the fittest and an elimination of the unfit.

Self-test on Problem XXI–C. **1.** Scientists believe it *possible* that *many* animals as simple as mollusks and cœlenterates hear.

2. Insects are believed to hear by means of organs located on (1) their heads; (2) their hind legs; (3) their front legs; (4) different parts of different insects; (5) their antennæ.

3. We hear *little* except when the bones of the middle ear vibrate.

4. In vertebrates the organ of __(?)__ is always located in the ear, but the organ of __(?)__ is not always present.

5. The hearing organ of mammals is *somewhat less* highly developed than that of the other classes of vertebrates.

6. There are *no* vibrations which man cannot hear.

7. We should find it *difficult* to maintain our balance, even though the organs of balance were perfect, if the nerves connecting these organs and the brain were destroyed.

8. There are various sorts of organs of *balance* located in various parts of different animals.

9. In general the *keener* the senses, the *greater* the chances for survival.

ADDITIONAL EXERCISES AND ACTIVITIES

Problem. Why have the bulging eyes of frogs a greater survival value than they would possess if they did not bulge? Besides the two eyelids the frog has a transparent third eyelid (nictitating membrane) which can be drawn up when the animal is under water. Of what survival value is this adaptation?

Exercise on Scientific Method. 1. Making Hypotheses. Can you think of an explanation which might account for the collapse of the leaves of the sensitive plant if it had a simple nervous system like the hydra? You may need to review pages 373–378.

2. Making Inferences and Proposing Experiments. Charles Darwin, the famous English scientist, in his book *A Naturalist's Voyage in H. M. S. Beagle,* describes an interesting experiment which another naturalist had tried with turkey buzzards. These birds eat decaying flesh, or carrion. The naturalist covered with a thick canvas cloth some flesh which had decayed sufficiently to have a very strong odor, and placed some pieces of meat on the cloth. "These the carrion-vultures ate up, and then remained quietly standing, with their beaks within an eighth of an inch of the putrid [decaying] mass, without discovering it." When a small tear was made in the canvas, the birds discovered the meat at once. But when "the canvas was replaced by a fresh piece, and meat

again put on it," this meat "was again devoured by the vultures without their discovering the hidden mass on which they were trampling." What inference would you draw from these observations? Why was this experiment repeated? Can you suggest other check experiments similar to this one which would enable you to tell whether your inference was correct? Would you approve the following as a conclusion from the experiment: "All carrion-eating birds would have reacted to the same situation just as did these vultures"? Justify your answer.

3. Inventing Experiments. It is said that we taste sweet substances at the tip of the tongue, sour substances at the sides, bitter at the very back, and salt all over. Plan an experiment to test the truth of this statement.

4. Making Inferences. Certain investigators placed a grasshopper in one end of a narrow glass tube and a hunting spider (Fig. 269, p. 413) at the other end. The spider's movements changed when it had advanced to within eight inches of the grasshopper, and at four inches it leaped upon its insect prey. How many possible explanations can you think of which might explain this behavior? Why can we not be certain that any of these explanations is the correct one?

5. Evaluating Conclusions. How many reasons can you give to explain these two statements: "It is very difficult to study the vision of animals, especially the lower ones. Practically nothing is yet known as a *fact* about how they see or how well they see"?

6. Making Inferences. When a mother hen finds food she makes a certain fairly high-pitched sound. The chicks immediately run to her and eat the food. When she sees a hawk flying overhead, she utters a low-pitched warning, whereupon the chicks scamper and hide. On the basis of these facts, would you accept this conclusion: "Birds are able to hear all sorts of sounds"? Justify your answer. Are these responses of the young birds learned or unlearned reactions? Justify your answer.

Reference Books

Gates, A. I. Elementary Psychology. The Macmillan Company, New York.
Robinson, J. H. The Mind in the Making. Harper & Brothers, New York.
Washburn, M. F. The Animal Mind. The Macmillan Company, New York.

UNIT VI · *Man's Efforts to Conserve his Energy through Control of Disease and Improvement of Health*

PROBLEMS DISCUSSED IN THIS UNIT

It would be difficult enough to fight successfully an animal, such as a lion or an elephant, which is as large as oneself or larger. But in such a struggle one would at least have the advantage of being able usually to see what one was fighting and to know when the attack was about to be made. It is usually more difficult to emerge victorious from the constant attacks of the millions of germs which cause various serious diseases. In such struggles one is unable to see the attacking foes or to know of an attack until it has been successfully made and its disastrous results are apparent.

Biological science is constantly engaged in the task of finding out more about disease germs in order to improve the means by which their attacks may be prevented or successfully resisted. This unit is devoted to a discussion of this scientific warfare. The major problems considered are these:

What is the nature of disease germs?
How are diseases spread?
How may we guard against attacks from disease germs?
What are the principles guiding the prevention and the treatment of some of the most serious germ diseases?
What are some applications of biological knowledge to health and hygiene?

Chapter XXII · Use and Control of Invisible Living Things

Questions this Chapter Answers

What is meant by a biological "friend" or "enemy"?
How did knowledge of bacteria grow?
What are communicable and non-communicable diseases?
How are communicable diseases spread?
Are communicable diseases inherited?
How may the body be guarded against attacks by disease germs?
How does the body acquire immunity to disease?
Can science aid the body in acquiring immunity?

Problem XXII–A · How do Various Microörganisms Help and How do they Injure Man?

Biological "friends" and "enemies." No organism except man and perhaps some of the higher animals helps or hinders another through intention. Friendship and enmity, as these words are applied to people, do not exist among living things in general. Each organism is engaged in its own struggle for existence. With few exceptions it takes advantage of every favorable condition in its environment without consideration for the welfare of other organisms. Certain of its activities may prove useful to other organisms; others may prove more or less harmful. But it must survive by its own efforts in the compe-

Fig. 277. A drawing of molds from an ancient notebook by Robert Hooke. **Special Report:** Consult an encyclopedia for facts concerning Hooke and his work

tition with all the other organisms. It is necessary to keep these facts in mind in speaking of friends and enemies among plants and animals. They are friends only in the sense that their activities are useful to us, and they are enemies only in the sense that their activities are injurious to us.

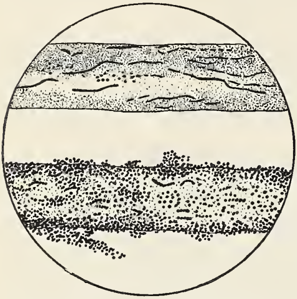


FIG. 278. Spores of the ringworm mold on human hair.[1] Special Report: What is the proper treatment of ringworm and "athlete's foot"? (Consult your family physician for facts)

Some of man's enemies among the lower organisms. It is difficult to realize that some of man's most active and powerful enemies are small organisms (Fig. 277). In fact, probably the most important are parasites, such as certain bacteria, molds, yeasts, rusts, smuts, and a few Protozoa. Bacteria cause most of the serious diseases. Molds cause ringworm of several types, including "athlete's foot" (Fig. 278). The spores of a few other varieties of mold upon entering the lungs are able to live there as parasites and in a few cases have caused death. Some diseases of the skin and lungs are caused by yeasts. Rusts and smuts attack some of our food plants. They are therefore of great importance to man because they compete with him for his food supply. Sometimes serious poisoning results from eating rye which has been attacked by smuts. Certain Protozoa are responsible for some of man's most dangerous diseases. Malaria and several other diseases, relatively rare in this country but common in the tropics, have been definitely traced to protozoan parasites.

Since bacteria are the most important of these organisms, the remainder of this chapter will be devoted chiefly to a discussion of bacteria and their relation to disease.

How knowledge of bacteria grew. A study of fossils proves that bacteria much like those of the present day lived on the earth many millions of years ago. Indeed, they are thought by some scientists to have been the first living things upon the earth.

[1] From Conn's *Bacteria, Yeasts, and Molds in the Home*. Ginn and Company.

Yet seventy-five years ago few people had ever heard of bacteria. Some of the scientists had learned to recognize a few forms under the microscope, but they considered the bacteria and all sorts of other tiny organisms of various kinds as belonging in one group. Practically nothing was then known about how the bacteria lived or what they ate. Bacteria were nothing more than scientific curiosities. They were interesting chiefly because, small as they were, they were nevertheless known to be living creatures. Nobody then suspected that they bore any relation to the welfare of man and other organisms.

Accurate scientific knowledge of bacteria dates from the work of such scientists as Cohn, a German, who published the results of his investigations during the period from 1853 to 1872, and Pasteur, a Frenchman, whose studies were reported during the same period. Pasteur proved that decay never occurs except as a result of the action of bacteria or other living organisms. The work of many scientists finally established beyond question the relation of certain kinds of bacteria to certain diseases.

Self-test on Problem XXII–A. **1.** An organism which competes with man for energy is called an __(?)__.

2. *All* enemies of man which are most dangerous are microscopic.

3. *Most* of the *bacteria* cause diseases in animals or plants.

4. The worst of these enemies of man are (1) bacteria; (2) yeasts; (3) molds; (4) rusts; (5) smuts.

Problem XXII–B · How are Communicable Diseases Spread?

***Communicable and noncommunicable diseases.** The communicable diseases, that is, those which can be contracted directly or indirectly from people who have them, are all caused by bacteria or other organisms. Such diseases are commonly called "germ" diseases, but the germs are not always bacteria. Sometimes, as has been stated, they are molds or yeasts, sometimes Protozoa, certain of the worms, or other parasites. There are, however, a number of very serious diseases which are not due to bacteria or to any other living organisms. These are probably

the result of the wearing out of various tissues and organs. These diseases include diabetes, diseases of the heart and of the kidneys, and hardening of the arteries (arteriosclerosis). They are known as noncommunicable diseases because they cannot be contracted from people who are sick.

***How communicable diseases are spread by people.** Most of the communicable diseases are contracted more or less directly from people who have the diseases. Whenever a person talks, he sprays into the air innumerable minute drops of saliva and mucus which are laden with bacteria. When he coughs or sneezes, the number of bacteria-laden particles and the distance to which they are discharged are both greatly increased. Hence, whether a person knows he is ill with a communicable disease or not, he should always protect others by covering his mouth and nose with a handkerchief whenever he coughs or sneezes. Spitting, like coughing or sneezing with the mouth uncovered, is neither a decent nor a sanitary practice, because it is a ready means of spreading disease.

Serious diseases (such as diphtheria, scarlet fever, tuberculosis) and colds can be readily contracted through kissing. A single kiss on the mouth has been known to transfer to a baby disease germs which later caused its death.

Some diseases are spread through the excreta[1] from a sick person, which are liable to contain germs. Hence these wastes should be sterilized with a germ-killing substance such as lysol, formaldehyde solution, or bichloride of mercury. Germs are also carried on clothing. Therefore the clothing worn by a person while he is suffering with a serious communicable disease should be sterilized, or, if this cannot be done, the garments should be burned.

There are certain people who are called "carriers of disease." Some of these people have themselves had a germ disease and have recovered from it, while others may never themselves have been sick; yet they carry the germs about and can infect other people. Most of them do not realize that they are a source of danger. Diphtheria and typhoid fever are two serious diseases which are readily spread by such carriers.

How communicable diseases are spread by animals. *As victims of the disease.* People sometimes contract serious diseases

[1] *Excreta* (ex kre′ta): the wastes from digestion; excrement.

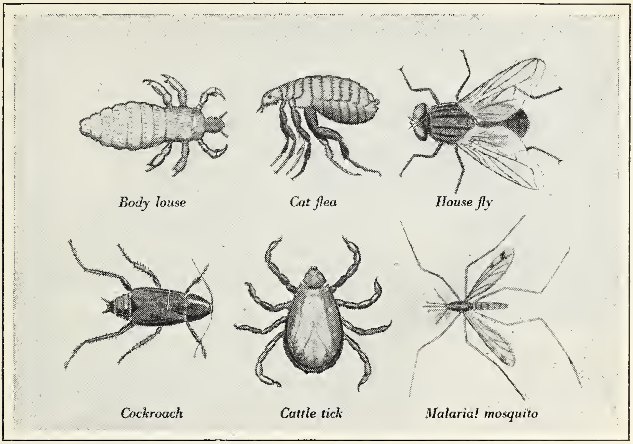


FIG. 279. Name one or more disease germs which each of these animals carries (see text, pp. 429–430)

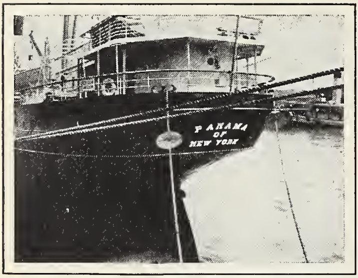
from household pets and domestic animals which are sick with the diseases and transmit[1] them to their owners just as would sick people. Cats, dogs, rabbits, guinea pigs, and birds are thus able to transmit diphtheria and other diseases.

As hosts of the disease parasite. Certain animals, such as the malarial mosquito (Fig. 279) and the yellow-fever mosquito, act as hosts for certain parasites which must live a part of their lives in these animals and the rest in the bodies of human beings. In such cases both the man and the mosquito are hosts of the parasite. Such diseases can be eliminated only by exterminating an animal carrier or by preventing its coming in contact with human beings. Yellow fever and malaria are discussed later in this chapter.

As carriers of insect parasites. Another class of animal carriers transmit serious diseases by harboring insect parasites which transfer the germs to man, although these carriers do not themselves serve as hosts to the germ. For example, bubonic plague is a disease of rats, ground squirrels, and sometimes of rabbits and guinea pigs, as well as of man. Man, however, cannot contract

[1] *Transmit* (trans mit′): to send from one place to another.

the disease directly from any of these animals. He must become infected with the bacteria through the bite of a flea, thus: If a flea bites an animal which is suffering from plague, it takes the plague germs into its digestive system. If later the flea bites a human being, the active germs in the flea's excreta may find their way through the wound made by the flea and thus gain entrance into the victim's body. This disease is common in China and especially in India, where it kills an appalling number of people every year. There have been occasional outbreaks in this country, but it has never become epidemic because of quarantine[1] and because the rodent carriers were killed in enormous numbers (Fig. 280).



Bureau of Public Health Service

FIG. 280. Rat guards on mooring ropes. What other ways can you suggest by which rats might be prevented from bringing plague germs into the country?

As mechanical carriers. Still other animals, such as flies, lice, and cockroaches, do not themselves act as hosts, but carry the germs on their feet and bodies or in their excreta. Such pests can be fought successfully only by keeping our bodies and clothing, our homes, schools, and places of business, as clean as possible, by screening, by destroying the animals themselves, and by destroying their breeding places. The house fly and the cockroach carry the germs of typhoid, tuberculosis, and many other dangerous bacterial diseases, and in addition carry several kinds of parasitic worms. Body lice, which thrive and multiply in filthy homes and upon filthy bodies, carry typhus fever, from which more than a million people have died since the close of the World War. Trench fever, less dangerous than typhus fever, but serious nevertheless, is also carried by body lice.

Pets which carry germs in their fur should be classed as mechanical carriers of disease.

[1] *Quarantine* (kwor'an teen): keeping apart by themselves those who have certain communicable diseases or who might carry these diseases to others.

***How communicable diseases are spread through water.** Even rain water may contain bacteria and other small organisms washed from the dust of the air. The germs of serious diseases, however, are not often found in water unless the water has become contaminated[1] with human excreta. Serious diseases which can be spread through drinking water are typhoid fever, cholera, and dysentery.

Some of the most serious epidemics of typhoid fever have started from a single patient whose excreta found their way into a city water supply. The toilets of trains and airplanes, unless equipped to retain the wastes, are liable to be the means of spreading such pollution into streams and lakes which serve as sources of water.

How communicable diseases are spread through food. Many diseases may be transmitted through food, among them typhoid, tuberculosis, scarlet fever, diphtheria, septic sore throat, and intestinal diseases of children. Probably the chief source of such infections is milk. The properties which make milk a valuable food for human beings make it also an ideal food for bacteria (Fig. 281). As a result most known varieties of bacteria may be found in milk. Butter and cheese, which are milk products, are unlikely to contain dangerous bacteria, except those of tuberculosis.

*Several precautions should be carefully observed in connection with the milk supply. (1) The cows must certainly be healthy. (2) The conditions in which the milking is done should be as sanitary as possible. (3) Those who work around the milk should be healthy. In some states and cities dairy and creamery workers are required to have certificates stating that they have no diseases which are liable to be spread through the milk (Fig. 282). (4) The milk should be protected from contamination while it is being prepared for distribution and is being sold. (5) The milk should be kept cool and clean after delivery to the homes as well as before.

Excepting perhaps the highest grades of raw milk, the only safe milk is that which is pasteurized. In this process the milk is heated to a temperature of about 140° to 150° F. for a period of

[1] *Contaminate* (kon tam′i nate): to make dangerously unclean or to pollute. *Contamination* (kon tam i na′shun): act of contaminating or state of being contaminated.

MILK-BORNE OUTBREAKS OF SICKNESS

NEW YORK STATE, EXCLUSIVE OF NEW YORK CITY

OUTBREAKS — NUMBER OF CASES — APPROXIMATE

Year	Typhoid and Paratyphoid		Diphtheria		Scarlet Fever		Septic Sore Throat		Dysentery		Poliomyelitis		Gastroenteritis		Total	
	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases
1917	3	53													3	53
1918	6	114													6	114
1919	4	48													4	48
1920	4	55	1	70											5	125
1921	10	211			1	24			1	14					12	249
1922	5	84	1	13	2	155									8	252
1923	8	83			1	59									9	142
1924	6	103			1	20							1	82	8	205
1925	6	137	1	16	2	44	1	366			1	8			11	571
1926	8	126	2	24	2	65							2	157	14	372
1927	2	15			1	5									3	20
1928	1	7			1	31							1	84	3	122
1929	1	7			1	6	3	225							5	238
1930							3	599					2	34	5	633
Total	64	1043	5	123	12	409	7	1190	1	14	1	8	6	357	96	3144

SOURCE OF INFECTION

1917-1930	Typhoid and Paratyphoid	Diphtheria	Scarlet Fever	Septic Sore Throat	Dysentery	Poliomyelitis	Gastroenteritis	Total Outbreaks
Carrier on farm	33	1		1				35
ditto — probable	16							16
Carrier at plant	1	1						2
ditto — probable	1							1
Case on farm	8	3	6	2 *	1	1		21
ditto — probable			2					2
Case at plant	1							1
ditto — probable	1							1
(Probably) returned bottles	1							1
Cows — udder infections			1	3			5	9
Not determined	2		3	1			1	7
Total outbreaks	64	5	12	7	1	1	6	96

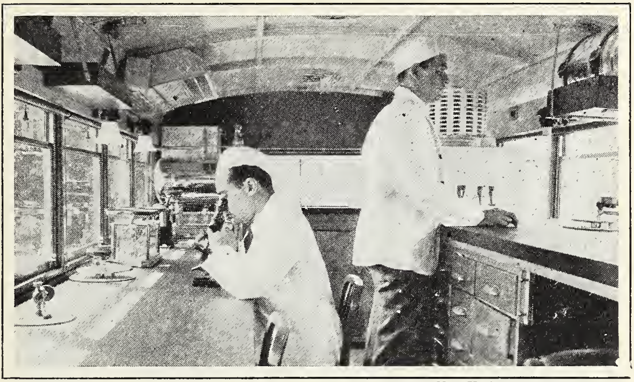
*Also case of mastitis in herd, in one outbreak.

FIG. 281. Which diseases were most frequently carried by milk? What were the chief sources of infection? How might these sources of infection be reduced?[1]

thirty to forty-five minutes. It is then cooled. This process kills most of the dangerous bacteria without injury to the milk as food.

Are communicable diseases inherited? It is a rather common belief that many diseases are inherited by children from their parents. This belief is true of only a limited number of diseases.

[1] *Public Health in New York State,* 1932, p. 465.



State of New York Department of Health

FIG. 282. A milk "Labmobile." What advantages has this laboratory?

It is now believed, however, that most cases in which the children of parents suffering from a communicable disease also have the disease are due to one of two causes: (1) either the children of weak parents may inherit a weakness of structure or organs which may make them an easier prey to the bacteria than normal children, or (2) the children, after they are born, contract the diseases from the parents. The latter is probably the chief cause.

***Summary.** The germs of communicable diseases gain entrance to the body mainly (1) through the respiratory system; (2) through the digestive system; (3) through the skin. Such germs are spread chiefly (1) by people sick with the disease, but they are also spread (2) by animals (*a*) which themselves have the diseases, (*b*) which act as intermediate hosts for the germ, (*c*) which act as necessary carriers of insect parasites, or (*d*) which act as mechanical carriers; (3) through the water system; and (4) through food, especially milk. Few diseases are inherited.

Self-test on Problem XXII–B. 1. *All* bacteria are germs, and *all* germs are bacteria.

2. *All* diseases that are "catching" are caused by organisms.

3. Sneezing with uncovered mouth and spitting are ways in which *noncommunicable* diseases are spread.

4. *Some* people are able to spread disease without themselves becoming sick.

5. Name and give an illustration of each of four ways in which animals spread diseases.

6. A disease which may be readily contracted from water which is polluted with sewage is (1) mumps; (2) rheumatism; (3) typhoid fever; (4) anemia; (5) rickets; (6) heart disease.

7. Select from the following the two items which do not belong with the rest: (1) typhoid fever; (2) trichinosis; (3) scarlet fever; (4) "athlete's foot"; (5) septic sore throat; (6) tuberculosis; (7) rickets; (8) diphtheria; (9) communicable diseases.

8. Name five ways of protecting the milk supply from dangerous disease germs.

9. *Many* diseases can be passed on to the child before it is born.

Problem XXII–C · How may we Guard against Attacks by Disease Germs?

* **Guarding the body against attacks from germs.** Bacteria and other organisms causing disease cannot produce disease unless they gain entrance to the body and to the particular organs or structures which they are able to attack (Fig. 283). Some protection can therefore be gained in the following ways: (1) by destroying bacteria which might cause disease; (2) by sterilizing all scratches and wounds, even the smallest; (3) by observing rules of personal cleanliness and of sanitation; (4) by quarantining of people who have dangerous, easily transmitted diseases; and (5) by insuring as nearly as we can that our food and water are free from harmful bacteria.

By destroying bacteria. Dishes should be thoroughly scalded always. In case some member of the family is suffering from some communicable disease, the dishes used by the sick person should be kept separate from those of the rest of the family and should be boiled after each meal. The discharges from the noses and mouths of patients suffering from colds, influenza, or other serious diseases should be deposited in paper handkerchiefs and later burned. The excreta of typhoid-fever patients should be dis-

FIG. 283. How do the modern methods of preventing disease differ from those claimed by this Indian medicine man?

infected[1] by the use of such a disinfectant as bichloride of mercury, formaldehyde solution, or lysol. All bed linen and the under-garments of sick people should be boiled; in fact, it is a sanitary practice to boil all garments in the family laundry which will not be injured by boiling and to use very hot water with the rest.

By sterilizing scratches and wounds. Tetanus is a dangerous disease, the germs of which enter through wounds. Other bacteria which cause infections enter through scratches and wounds. Tincture of iodine is an almost certain means of killing germs in a small wound or scratch, but it has the disadvantage of being extremely painful. A further disadvantage is that the alcohol, in which the iodine crystals are dissolved, evaporates readily. As a result the iodine in the solution tends to become more strongly

[1] *Disinfect* (dis in fekt'): to kill the germs in or upon an object. *Disinfection* (dis in fek'shun): act of disinfecting. *Disinfectant* (dis in fek'tant). a substance which kills germs.

concentrated, until sometimes it burns and injures the tissues. In spite of its disadvantages, however, tincture of iodine of the proper strength is probably the best household germicide.

Cleanliness Institute

Fig. 284. Inspection of hand-washing before entering the school cafeteria. What provisions for hand-washing have you in your school?

By observing rules of cleanliness and sanitation. Germs thrive in filth. Dirty clothing and dirty homes are liable to harbor innumerable bacteria. Hands, touching, as they do, all sorts of germ-laden things, are certain to be covered with bacteria. The use of plenty of soap and water is a good safeguard of health (Fig. 284).

An important step toward sanitation is the elimination of flies. These breed in open outdoor toilets, manure piles, garbage piles, or any other deposits of filth. The vaults of outdoor toilets should be made and kept fly-tight and should be frequently sprinkled liberally with chloride of lime or dust. Barnyard manure should be kept in fly-tight boxes or bins until it can be spread upon the ground. If spread thinly it soon dries. Flies cannot breed in dry filth. Garbage and other refuse should be collected frequently and regularly and should be buried, burned, or otherwise disposed of.

Disease germs are spread by dust. The sweeping of bare floors should therefore be done with a dampened broom or an oiled dust mop. The sweeping of carpets and rugs should be done with a vacuum cleaner, and the contents of the dust bag should be burned. Dusting is most effectively and safely accomplished by the use of an oiled dust cloth or a treated dusting paper.

**By quarantining.* In most places quarantine is demanded by law in cases of serious communicable diseases, such as smallpox, diphtheria, scarlet fever, and many others. If the patient remains at home, the members of the household are not permitted to

leave the house, nor are visitors allowed to enter it. In the hospitals are special "contagious wards," where those sick with serious communicable diseases are kept away from others who might contract the diseases. Those who have been exposed to one of several of the diseases which are most serious and easily carried are often quarantined, even though they have not yet shown any symptoms[1] of the disease.

Quarantine regulations are necessary for the good of the community as a whole and are observed in every requirement by all good citizens. Serious consequences are liable to result if quarantine is broken. Several years ago, during an epidemic of smallpox in a Western town, a man left the quarantined area in order to attend to some business matters in other towns. A few days later he became ill with smallpox. But before he could be quarantined, he had exposed hundreds of people to the disease. As a result of his selfish indifference to the welfare of others, many who had been exposed took the disease from him and several died.

Quarantine should be observed in the home as much as is possible in the case of the sickness of any member of the household. The common cold would be less common if the sufferer were kept as much as possible away from other members of the family, from the time the first symptoms of the disease appear until he has recovered.

Self-test on Problem XXII–C. **1.** State five ways in which one may protect oneself from disease germs.

2. The house fly is responsible for the spread of (1) rheumatism; (2) heart trouble; (3) yellow fever; (4) typhoid fever; (5) jaundice; (6) trichinosis.

3. It is *usually* wise to sterilize a scratch or small wound.

4. A disease for which quarantine is required by law is (1) typhoid fever; (2) heart trouble; (3) diphtheria; (4) jaundice; (5) rheumatism; (6) trichinosis; (7) cold.

5. A disease for which quarantine is desirable is (1) heart trouble; (2) tapeworm disease; (3) rheumatism; (4) jaundice; (5) trichinosis; (6) cold.

[1] *Symptom* (simp'tum): something which indicates the existence of a condition, as a disease.

Problem XXII–D · How may the Body be Helped to Resist Attacks of Disease Germs?

***How the body resists attacks from germs.** The body is constantly being attacked by germs of various kinds. It has there-

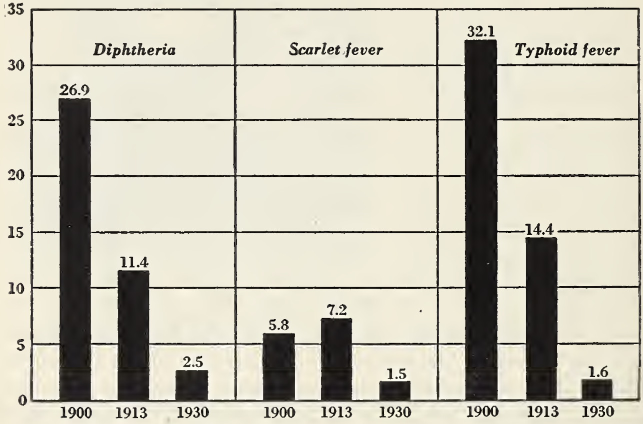


Fig. 285. Death rates per 100,000 population from various diseases in New York State. Which of these diseases has shown the greatest decrease in death rate over a period of thirty years? [1]

fore had to develop means of defense. These natural means have enabled man to survive as an organism. But medical science has found ways of increasing the resistance to disease. It has learned how to stimulate the body to build defenses which, with several of the most serious diseases, are more effective than those which the body has developed of itself. Now when the proper safeguards provided by science are used, there is relatively little danger either of contracting diphtheria, smallpox, and typhoid fever or of suffering severely even if one does (Fig. 285). The body resists disease because of natural immunity[2] or of acquired immunity.

[1] Data from *Public Health in New York State,* 1932.

[2] *Immune* (im mune′): protected against or exempt from any particular disease. *Immunity* (im mu′ni ty): state of being immune. *Immunize* (im′u-nize): to make immune.

Natural immunity due to structures and secretions. The healthy body has many natural means of defense against invading germs. The unbroken skin and the unbroken mucous membranes afford excellent protection against the entrance of germs. And certain special secretions of the respiratory and the digestive systems are to some extent germicidal.[1] These are the mucous, the salivary, and the digestive secretions, especially the hydrochloric acid in the gastric juices. Even tears, secreted by the tear glands, are somewhat germicidal and serve to protect the eyes against infection. Entrance to the respiratory system is guarded to a considerable extent by the hairs in the nose and by the hair-like cilia in the passages of the lungs. The germs which manage to find their way past all these defenses into the blood are there met by an army of white corpuscles. There are also certain tissue cells which can engulf bacteria from the blood in much the same way that the body cells of the sponge and the hydra capture food. Often even when germs — for example, those of tuberculosis — succeed in reaching the lungs of healthy people, the lung cells build a wall around the germs, thus holding them helpless prisoners.

Germs, when attacking the body, throw toxins, or poisons, into the blood stream. All the living cells manufacture substances called antitoxins, which resist, or counteract, the toxins. The cells, moreover, are able to manufacture certain substances other than antitoxins which enable the body to resist disease. Certain of these substances, called agglutinins, cause the invading bacteria to gather together in masses. As a result their harmful action is prevented or at least greatly diminished. The body manufactures an agglutinin as a means of defense against typhoid fever. Still other substances (the opsonins) act upon bacteria in such a way that the white corpuscles will engulf the bacteria in far greater numbers than if these substances were not present in the blood. All these various substances which the cells manufacture as a means of combating disease germs are called antibodies.

Natural immunity due to other conditions. It is a well-known fact that certain people, as well as certain animals, contract diseases more readily than do others, and that a person or an animal may contract certain diseases readily but may be immune to

[1] *Germicidal* (jur'mi sid al): germ-killing.

the attacks of others to which he or it has been equally exposed. Such ability to fight off disease attacks is called natural immunity. There are several kinds of this sort of natural immunity: (1) Sometimes the immunity is related to a particular organism. For example, man is naturally immune to many diseases of animals, as chicken cholera or the cattle disease Texas fever. (2) It is related to species or, as we say in connection with human beings, to race. Thus the Chinese have a natural immunity to scarlet fever which is very much greater than that of other races of men. The white race has a much greater natural immunity to smallpox than has the Indian. (3) It is sometimes related to family. Thus the members of certain families have a much greater natural immunity to certain diseases than the members of other families. (4) It is related to the individual. Thus one member of a family may readily contract mumps, scarlet fever, or other diseases, while other members of the same family may nurse the sufferer without contracting the disease. (5) It is related to age. There are certain diseases, such as diphtheria, scarlet fever, and measles, which are diseases of children and are seldom contracted by adults. (6) It is related to one's health. Thus one may be exposed to a disease many times before one contracts it.

***Immunity acquired from having the disease.** Most of the serious bacterial diseases can be contracted only once during one's lifetime. Having these diseases renders one immune, because the antitoxin and other substances manufactured by the body in recovering from the disease remain for a considerable time, sometimes for life. Thus one need never fear a second attack of smallpox, and few people can contract measles or scarlet fever a second time. Other diseases give immunity for long or short periods, depending on the individual. Thus while immunity to diphtheria for some people lasts for life, for about half the patients it lasts only a year or less.

Foolish as it is, there are many people who welcome diseases in young children in order to secure for them the immunity which may come from having had the diseases. Thus one may hear a mother say, "I want my children to have all the children's diseases early, so that there will be no reason to fear these diseases later on." She may even purposely expose her children to mea-

sles, whooping cough, chicken pox, and other diseases. Such practice is unscientific for two reasons: (1) It assumes that everybody is certain sooner or later to contract at least all the commoner diseases. (2) It assumes that the diseases are less serious with children than with adults. We know that the first belief is unsound, because with certain diseases, such as meningitis, measles, scarlet fever, and diphtheria, natural immunity increases as one becomes older. In the outbreak of infantile paralysis in New York in 1916, more than 90 per cent of the cases were children under five years of age. These facts indicate clearly that if one escapes these diseases as a child, he has a good chance to escape them during his entire life.

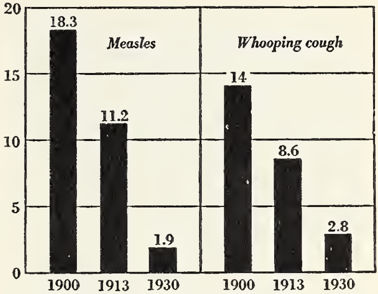


Fig. 286. Deaths from measles and whooping cough per 100,000 population in New York State. What reasons can you suggest to account for the decrease in death rates of these diseases?[1]

We know that the second belief is not sound, because certain diseases are often fatal to children but seldom to adults. From 90 to 95 per cent of all deaths from measles are of children under five years of age. With whooping cough, the younger the child the greater the chance of death from the disease. Thus hospital records show that from 20 to 35 per cent of all children under one year of age who are treated in the hospitals die of the disease (Fig. 286).

Immunity acquired from inoculations.[2] As has been previously stated, disease germs produce poisons called toxins. These are the excretions and secretions of the germ resulting from its life processes as it feeds upon the body tissues. The presence of a

[1] Data from *Public Health in New York State*, 1932.

[2] *Inoculate* (in ok′u late): to inject into the body some substance for the purpose of preventing or curing a disease. *Inoculation* (in ok u la′shun): act of inoculating.

toxin in the blood stimulates every living cell to manufacture antitoxins. These unite chemically with the toxins, rendering them harmless. If the blood contains a sufficient quantity of the antitoxin of a certain disease, the person is immune to that disease, because the toxin is neutralized as soon as it enters the blood. Each antitoxin, however, can neutralize only one kind of toxin. The cells must therefore manufacture a special antitoxin for every disease that attacks the body.

*It is probable that the blood always contains some of the antitoxins for every disease to which the person has been exposed. These antitoxins have been produced probably as the result of very mild attacks which the body was able to overcome. But such quantities of antitoxin as the blood may naturally contain may not be sufficient to insure that the person will be immune. Several means have been found, however, for stimulating the cells to produce additional quantities of antitoxins. The means vary for different diseases. For certain ones, some of the toxin of the disease is introduced into the body in very small quantities or in a weakened form. For others, living but weakened germs are introduced. For still others, dead germs are used. Immunity acquired by any of these means may last from a few days to many years or in some cases as long as one lives, depending upon the disease and other factors.

Medical science has also found means in the cases of several dangerous diseases, including diphtheria, smallpox, and typhoid fever, of determining whether the blood contains a sufficient quantity of antitoxins to resist attacks from these diseases. If these tests show that the quantity is not sufficient, inoculations can be given which will stimulate the cells to increase the supply of antitoxin and consequently to insure the person's immunity.

Factors affecting immunity. One's immunity to diseases varies from time to time for a number of reasons in addition to those previously given. For example, one's immunity is certain to be less (1) if one is very tired either from physical or from mental work; (2) if one has become chilled from exposure; (3) if one has been living where there have been overcrowding, filth, and poor ventilation; (4) if one has not had enough of the right kinds of food, containing sufficient supplies of energy, building ma-

terials, and especially vitamins; and (5) if one is weakened from a recent attack of some disease. One can therefore increase one's immunity through healthful living. One should keep regular hours and have plenty of sleep, fresh air, sunshine, rest, and play (Fig. 287).

Fig. 287. How does outdoor exercise promote good health?

Helping the body overcome disease attacks. Even after one has become ill, it is possible with a number of the diseases to assist the body in overcoming the attack by inoculating it with a serum containing quantities of antitoxin. These serums are usually obtained from the blood of young horses, cows, or goats which have been given mild attacks of the disease.

***Summary.** Human beings are constantly open to attacks from disease parasites. We can escape some of these attacks by living under sanitary conditions and by avoiding people known to be suffering from communicable diseases. The body has a number of means of avoiding attacks. It has some means of destroying invading germs, and it has some means of combating the toxins. Immunity and the ability to recover from certain diseases can be increased by various forms of inoculations. Immunity can also be increased through healthful living. All forms of increased immunity and of increased power to recover from disease attacks come only from increasing the natural defenses of the body.

The various means of increasing immunity and of assisting the body when attacked will be illustrated more fully in the following chapter, which deals with specific diseases.

Self-test on Problem XXII–D. 1. Name six factors upon which natural immunity depends.

2. Select from the following words or phrases the one which does not belong with the rest: (1) mucus; (2) cilia; (3) tears; (4) gastric juices; (5) white corpuscles; (6) whole skin; (7) urea.

3. It is *wise* to expose children to the common diseases while they are young.

4. Name five conditions which may determine whether or not one will become ill of communicable diseases.

5. A substance manufactured by protoplasm to counteract a poison produced by a disease is an __(?)__.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Which conditions favorable to the growth of bacteria occur in the human body?

2. Why should one avoid as much as possible crowded, unventilated rooms?

3. Typhoid fever has been known in some cases to be contracted from eating raw oysters. Can you explain how the oysters might have become contaminated?

4. How many ways can you list in which food and drinking water may be protected from contamination?

5. Why is it better never to have had such diseases as scarlet fever, whooping cough, and diphtheria?

Exercise on Scientific Method. 1. Evaluating Experiments. Louis Pasteur (1822–1895), a famous French chemist and biologist, made more important scientific discoveries which contribute to human welfare than any other scientist in the world's history. He began his scientific investigations as a chemist but made his chief reputation as a bacteriologist.[1] His earliest experiments, which were upon the causes of fermentation, were of immense value to the wine and beer industries. In connection with these experiments he produced evidence which was important in the overthrow of the "theory of spontaneous generation." Later he found the cause and suggested a cure for the silkworm disease, which had nearly ruined the silk industry in France and Italy. He is most famous, however, for his discovery of the method of curing disease by inoculating a patient with a weakened culture of the bacteria that cause the disease.

[1] *Bacteriologist* (bak te ri ol′o jist): a scientist who studies bacteria. *Bacteriology* (bak te ri ol′o jy): the science of bacteria.

Experimenting first with diseases of animals, such as chicken cholera and anthrax, he extended his treatment to human beings. His most famous achievement was the discovery of a cure for hydrophobia.

From encyclopedias and biographies find and list the scientific methods which Pasteur followed in his work. What native qualities did he possess which made him a successful investigator? What is the story of his study of wine fermentation? of the silkworm disease? of anthrax? What is the story of the boy Jufille and Pasteur's successful attempt to cure him of hydrophobia?

2. Making Hypotheses. Adult city dwellers have a greater natural immunity to scarlet fever than adult country dwellers. How many possible reasons (hypotheses) can you state which might account for this fact?

3. Applications of Methods to New Situations. Robert Koch (1843–1910), a German bacteriologist, is famous for his investigations of diseases caused by bacteria. His first notable work was upon anthrax. Later he discovered the germs of tuberculosis and Asiatic cholera. He also made notable studies of bubonic plague, sleeping sickness, and malaria. In 1882 he invented the method still used for investigating the cause of a disease. Koch's method consists of four steps: (1) examine the blood and tissues of the diseased animal or person until some organism is found which is not found in normal tissues; (2) make a pure culture of this organism; (3) introduce some of the germs from this culture into the blood or tissues of a normal animal, and observe the animal to note whether it becomes sick of the disease; (4) examine the blood or tissues of this diseased animal to see whether the suspected organism is present in them. If it is present, one may be reasonably certain that the organism was the cause of the disease.

What is the story of tuberculin? Do Koch's four steps provide for controls? Explain.

Exercise on Scientific Attitudes. Joseph Lister (1827–1912), an English surgeon, introduced modern practices in the treatment of open wounds. Appalled by the high percentage of patients who died from infections following surgical operations and from wounds of all sorts in which the skin was broken, he carried on long and patient investigations to find ways of insuring normal healing. Building upon two facts which had been established largely through the work of Pasteur, — namely, that all decay of organic matter is due to living organisms and that microörganisms are produced by organisms like themselves,— he decided that infection could be prevented by keeping the wound, the operating instruments, and the bandages free from living bacteria. Lister's experiments had a powerful influence upon modern surgical practice.

What investigations led Lister to give up the idea that wounds are infected by the air? (Consult an encyclopedia or a history of science.) What scientific attitudes (pp. 12–13) are illustrated by Lister's work?

Special Reports. **1.** Lister's surgical practice put more emphasis upon antiseptic surgery than upon aseptic surgery. Modern surgery stresses aseptic practice. What is the distinction between antiseptic and aseptic surgery? Consult an encyclopedia or your family physician for facts.

2. Secure from your family physician a list of noncommunicable diseases other than those mentioned here.

3. What is the story of "Typhoid Mary"?

4. How serious were the results of typhus fever and trench fever during the World War?

5. What are the various grades of milk sold in your city?

6. Describe the process of pasteurization in your city. Is homogenized ice cream made in your city? If so, how is it prepared? How is dry milk produced, and what are its uses?

7. How is garbage disposed of in your city? How is sewage disposed of in your city? (Consult the local board of public health.)

8. What are the quarantine regulations in your city? What are the quarantine regulations for immigrants into this country?

9. How is Texas fever combated?

Question for Debate. *Resolved,* That all persons known to be carriers of disease should be confined to an institution for the length of their lives.

How the Antitoxin was Brought to Nome

EARLY in 1925 Nome, Alaska, was stricken with diphtheria. The limited supply of antitoxin serum was exhausted almost at once. Without more, the city faced a desperate situation. The nearest railroad point was Nenana, six hundred fifty-five miles away. The ice prevented boats from reaching Nome. Airplanes tried to reach the city but failed. Serum could be brought only by relays of dog teams over the snow, ice, and the frozen shores of Bering Sea. Experienced and skillful drivers and relay teams of the best dogs were chosen, and the fearful day-and-night race was started against disease and death.

Five drivers in turn took the precious serum the first five hundred miles. Seppala, the next driver, was warned not to cut across Norton Sound, because the ice was already breaking up and drifting to sea. But because the safer route around Norton Bay would require two more days, Seppala, guided by his gallant lead dog Togo, boldly crossed the dangerous heaving ice.

When the package reached Gunnar Kasson at Bluff, a blizzard had developed so fierce that the most experienced "mushers" believed it impossible for man and dogs to face it or to keep the trail. But Kasson started, at times scarcely able to see his nearest dog. He became lost, as did also his lead dog. He then put Balto, his alternate lead dog, in the lead and ordered him to "go home." Despite the eighty-mile gale Balto kept steadily on over snowdrifts, bare frozen ground, and the glare ice of the lagoons. Kasson reached Nome in the early morning, February 2, 1925, himself and his dogs half frozen. The nine-day trip had been made by the eight drivers in five and a half days!

Because of their heroic parts in this race, Balto and his five teammates were given a home in Brookside Park, Cleveland, where Balto died in 1933.

FIG. 288. Gunnar Kasson, Balto, and Balto's statue in Central Park, New York City

Chapter XXIII · How Science Combats Certain Germ Diseases

Questions this Chapter Answers

Can disease be reduced?
What are the various methods used by science in combating diphtheria?
What means are used in fighting smallpox?
How can typhoid fever be controlled?
How is the danger from tuberculosis being reduced?
What progress is being made in combating malaria and yellow fever?

Problem XXIII–A · How does Science Combat Diphtheria, Smallpox, and Typhoid Fever?

Disease can be reduced. The diseases diphtheria, smallpox, typhoid fever, tuberculosis, malaria, and yellow fever have always been regarded with dread. During the years that have passed since they were first definitely recognized, so that records could be kept of them, each has been responsible for a serious amount of sickness and death. They are still formidable. But medical science has been improving its means of defense. Such great progress has recently been made in reducing the sick rate and the death rate from these and other diseases as to justify the hope that if the program of prevention and treatment outlined by the scientists is intelligently followed, these diseases can be practically eliminated in a relatively short time.

The preceding chapter was devoted to a discussion of germ diseases in general and the principles guiding their prevention and treatment. In this chapter these principles will be illustrated in connection with the dangerous diseases just mentioned.

***Diphtheria.** The progress in the fight against diphtheria has been accomplished through three medical triumphs: (1) the use of antitoxin, (2) the perfecting of a test of immunity, and (3) the use of toxin-antitoxin in producing immunity.

The use of antitoxin in the treatment of diphtheria became general in 1894. Before that time from 30 to 50 per cent of all who contracted diphtheria died. At present, through the use of antitoxin, the disease is fatal to only 6 to 8 per cent. The person who has contracted diphtheria can in most cases be cured by injections of the antitoxin, usually into a muscle or in severe cases into both a muscle and a vein. It is important that the treatment be begun as early as possible, since the antitoxin has less effect the longer the disease has run. The reason is that the antitoxin neutralizes the toxin as it is produced by the bacteria. But if the toxin has had an opportunity to combine with various tissues, especially those of the heart, then the antitoxin cannot repair the damage already done. It can, however, prevent further damage.

The antitoxin is prepared from horse serum. A small dose of diphtheria toxin is first injected into a guinea pig weighing 250 grams. If the animal dies within four days, the toxin is of the proper strength to administer to a healthy young horse. The cells of the horse immediately begin to manufacture antitoxin to neutralize the toxin. Later the blood containing the antitoxin is drawn from the horse without injury to the animal. The clot containing the blood corpuscles is removed, leaving the clear serum containing the antitoxin. Some of this serum mixed with toxin is injected into a healthy guinea pig. If the guinea pig lives, the serum is considered ready for use with human beings.

In 1913 the Schick test was introduced. By means of this test it is possible to determine whether a person is immune to diphtheria. A small dose of the diphtheria toxin is injected beneath the skin. If the patient is immune, nothing happens, because the antitoxin in the blood quickly counteracts the poison. But if the patient is not immune, a brown spot develops at the point where the toxin was injected. Such persons can then be made immune for several years and perhaps even for life by being inoculated with toxin-antitoxin thus: A mixture of diphtheria toxin and almost enough antitoxin to neutralize it are injected under the skin of the arm. The treatment is repeated from three to five times, at intervals of a week, until the Schick test, when repeated, shows the person to be immune.

Since young children are most liable to contract diphtheria, the toxin-antitoxin immunity treatment should be given before the child goes to school. The best age is from six to eighteen months (Fig. 289). Children with diseased tonsils are specially apt to contract diphtheria. Often the removal of the tonsils will render a child immune to the disease.

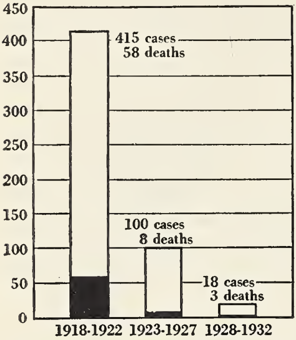


FIG. 289. Results of the diphtheria-prevention campaign in Auburn, New York. The work of administering the Schick test and toxin-antitoxin immunizing treatment was begun in the spring of 1922. Does such health work pay?

Recently a new method of immunizing people to diphtheria is being tried with success in place of toxin-antitoxin. This method consists in injecting under the skin some diphtheria toxin which has become weakened by having been kept a long time, by having been heated to 54° C., or by having been mixed with chemicals (formaldehyde). This weakened toxin (called a toxoid) is said to make a greater percentage of people immune to the disease than does toxin-antitoxin.

* Though diphtheria still remains a dangerous disease, the antitoxin treatment, combined with the use of the Schick test of immunity and of toxin-antitoxin to immunize those liable to contract the disease, has greatly diminished both the number of cases and the number of deaths (Fig. 290).

Smallpox. It is claimed that smallpox was known in China a thousand years before Christ. From that time until vaccination became a common practice, smallpox was probably the most feared and dreaded of all diseases.

Smallpox is said to have been introduced into America by a Negro slave who accompanied the Spanish conqueror Cortez to Mexico in 1519. Sweeping over the country, it found easy victims among the Indians, sometimes killing every member of a tribe. It is stated that as late as 1750 in certain countries of Europe, half the people contracted smallpox during their lives,

one tenth died, and one tenth were disfigured for life. Now in those states and countries in which vaccination is compulsory,[1]

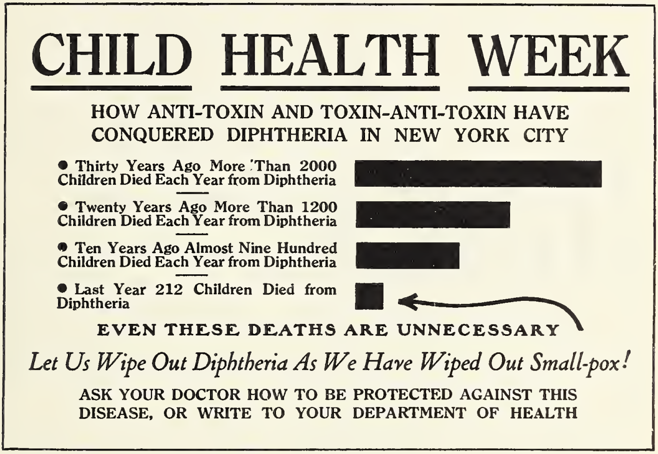


FIG. 290. This information was placed in electric cars by the Department of Public Health of New York City in the spring of 1933. Compare these facts with those concerning diphtheria in Auburn (Fig. 289)

the danger from smallpox has been so greatly reduced that it is no longer considered to be one of the most deadly diseases.

Cattle which have contracted cowpox, a disease of cattle similar to smallpox and possibly identical with it, have from the earliest days of vaccination served as the chief source of the vaccine, or virus.[2] Often, however, even in fairly recent times, the virus was obtained from people. In this way other diseases — for example, tetanus — were transmitted along with the smallpox virus.

The vaccine is now secured from young calves. A portion of the belly is inoculated with the virus. After five days the "pocks" have developed all over the inoculated area. The calf is then killed, and the virus from the pocks is drained into containers which have been thoroughly sterilized. A mixture of 50 per cent

[1] *Compulsory* (kom pul′so ry): required by law; not avoidable.

[2] *Virus* (vi′rus): a living animal poison produced by a disease germ and capable of transmitting the disease.

glycerin, 49 per cent water, and 1 per cent carbolic acid is now added to the virus. The glycerin and carbolic acid kill any live germs which may be in the virus. After the mixture has stood for four weeks, it is carefully tested to be certain that it contains no harmful organisms. It is now ready for use as a vaccine.

*Vaccination consists in introducing a little of the serum, or vaccine, into a scratch in the skin. If the person is not immune to smallpox, a single pock forms at the point where the vaccine was introduced. This pock goes through various changes until after about eighteen days the scab comes off, leaving a scar.

*Vaccination gives immunity in nearly every case. This immunity usually lasts about six years. If the vaccination is then repeated, the immunity is likely to last for life. Vaccination even after one has been exposed to smallpox has been found of benefit in making the disease less severe. Whether one has been successfully vaccinated or not, one should be vaccinated again in the event of an outbreak of the disease or before going to foreign countries where the disease is common.

Scientific evidence shows beyond doubt the value of vaccination. In Germany, for the fifty-year period before vaccination was made compulsory, the average yearly number of deaths from smallpox was 6663. Smallpox cases in Germany now are rare and are usually introduced by foreigners. Similarly in Sweden the death rate for smallpox was decreased from 2050 per million inhabitants before vaccination to only 158 per million after vaccination. In the United States, however, there is no national compulsory vaccination law. Six states have no vaccination laws whatever, and in only fourteen are the children compelled to be vaccinated before they are allowed to attend school. A comparison of the number of cases of smallpox in states having compulsory vaccination laws with those in states having no such laws should convince everybody of the great value of vaccination (Fig. 291).

Typhoid fever. Immunity to typhoid may be secured through vaccination similar to that for smallpox. The vaccine for typhoid, however, consists of the dead bodies of the typhoid germs. The germs are grown in an agar culture. They are then killed by heat. A small quantity of carbolic acid added to the vaccine preserves it.

The vaccine is administered three times, with intervals of one week between inoculations. The immunity thus secured usually lasts about two and a half years.

A test (Widal's test) has been developed which, before the disease has become sufficiently advanced to be easily recognized, indicates whether one has it or not. Several drops of blood of the person suspected are allowed to stand until the serum separates. This serum is diluted by adding a weak solution of salt. Living typhoid bacteria are then added. If the disease has already become active in the system, the typhoid bacteria will immediately gather together in groups, thus indicating that the body has already begun to manufacture the particular agglutinin which is needed as a defense against this particular disease.

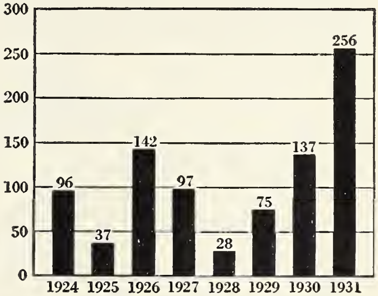


FIG. 291. This figure shows how many times as many cases of smallpox per 100,000 population occurred in California as occurred in Pennsylvania. There is a compulsory-vaccination law in Pennsylvania but none in California. How many reasons can you suggest which might explain why there has been an increasing difference in the number of smallpox cases in Pennsylvania and California from 1928 to 1932?

Self-test on Problem XXIII–A. **1.** People can usually be cured of diphtheria by injections of (1) toxin; (2) antitoxin; (3) cow serum; (4) vaccine; (5) toxin-antitoxin; (6) weakened toxin.

2. People can usually be rendered immune to diphtheria by injections of (1) toxin; (2) antitoxin; (3) cow serum; (4) vaccine; (5) toxin-antitoxin; (6) blood.

3. It is usually possible to determine whether a person is immune to diphtheria by the use of the __(?)__ test.

4. People can usually be rendered immune to __(?)__ by means of vaccination with virus secured from young calves.

5. A disease from which immunity is usually obtained by vaccination with dead bacteria of the disease is (1) smallpox; (2) typhoid fever; (3) tuberculosis; (4) scarlet fever; (5) measles; (6) trichinosis.

Problem XXIII-B · How does Science Combat Tuberculosis?

Tuberculosis. At about the beginning of this century tuberculosis was responsible for more deaths in the United States than

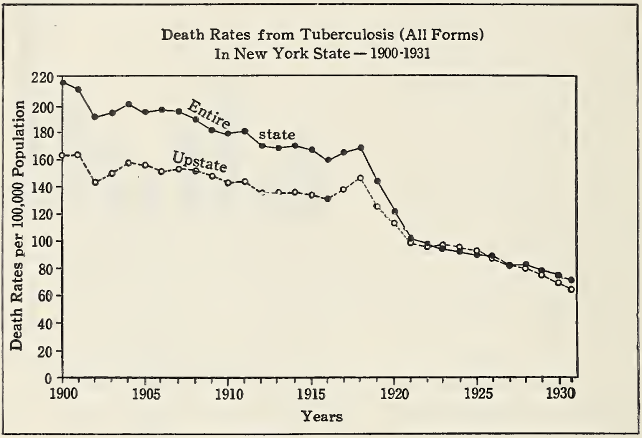
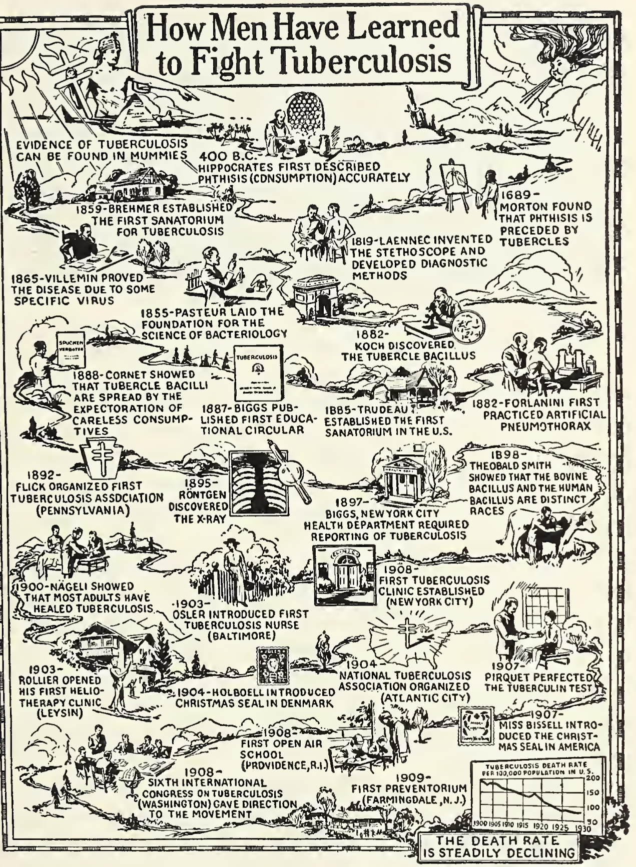


FIG. 292. Death rates per 100,000 population from tuberculosis (all forms) in New York State, 1900–1931. Has the death rate in New York State been increasing or decreasing? Has it been changing more rapidly in New York City or in the rest of the state?[1]

any other single disease (Fig. 292). Because it was so common and so deadly it was known as "the great white plague." During the past quarter-century its death rate has been steadily declining (Fig. 293). It now has seventh place among deadly diseases in the United States. Yet there are a million and a half cases from which there are about one hundred fifty thousand deaths annually.

Tuberculosis may attack the lungs, the glands of the neck, the skin, or the bones and joints. The disease is usually contracted during childhood, though it may develop so slowly that for many years the patient is not aware that he has it. After the patient is grown, it may become active, with the result that most of the sufferers die in early middle age.

[1] *Public Health in New York State,* 1932, p. 195.



National Tuberculosis Association

Fig. 293. About how many times greater was the death rate in 1900 than in 1929?

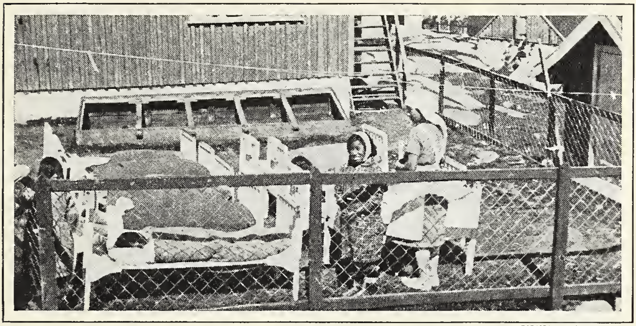
*Tuberculosis is not inherited. The children of tuberculous[1] parents, however, may inherit weaknesses which make them an easier prey to the disease, or they may contract it directly from the diseased parents. People contract tuberculosis chiefly (1) by eating food upon which the living bacteria from the discharges of tuberculous patients have settled or upon which flies carrying the bacteria have lighted; (2) by drinking milk or eating butter from tuberculous cows; (3) by handling objects which tuberculous persons have handled. Tuberculosis is also transmitted (4) through the air. People who spend much of their time out of doors are less liable to the disease than are those who live mostly indoors.

The form of tuberculosis which is spread by milk from cows having the disease is especially dangerous to children. This form of the disease attacks the lymph glands and the bones, but rarely attacks the lungs. The development of pioneer work by Koch has resulted in tests which can be applied to cattle to determine whether they are suffering from tuberculosis or have had the disease. In many states of the United States the killing of all animals which as a result of this test are proved to be tuberculous is required by law. In some states part of the value of these animals is paid to the farmer by the state.

Recently a method of vaccination of cattle has been introduced which gives promise of eliminating the danger from tuberculosis in cows. Calves are vaccinated before they are fifteen days old and again once every year. Although not enough cattle have yet been vaccinated in this way to justify a positive statement regarding the value of such vaccination, nevertheless the favorable results already secured encourage the hope that cattle thus treated are rendered immune.

Recently vaccines have been developed for the purpose of making human beings immune to tuberculosis. The most successful vaccine contains living bacteria which have been weakened so that they cannot produce the disease. Thus far, however, the results have not been especially successful, though it is believed that babies have gained some protection from the vaccination. A test similar to the Schick test for diphtheria has been developed also for tuberculosis.

[1] *Tuberculous* (tu bur'ku lus): sick with tuberculosis.



William S. Carlson

Fig. 294. An Eskimo tuberculosis hospital in Greenland. How many of the conditions necessary for the treatment of tuberculosis are evident here?

*It was formerly thought that there was no cure for tuberculosis. Now it is known that if the proper treatment is begun during the earlier stages of the disease, there is a very good chance of recovery. The patient should have complete rest, plenty of fresh air, sleep, sunshine (Fig. 294), and a well-balanced diet with a plentiful supply of vitamins. These all help to build up the bodily resistance, so that the bacteria can do no harm. Through prevention and proper treatment the number of cases and the number of deaths from tuberculosis are steadily declining.

Now that the nature of tuberculosis and the ways in which it may be spread are known, much can be done toward preventing its spread. One can protect oneself to a considerable extent by keeping one's body resistance high through observing the rules for healthy living. One can have a thorough physical examination every year (Fig. 295), so that the disease, if present, can be detected in its earlier stages. The patient suffering from the disease can protect others by covering his mouth and nose when coughing or sneezing, by not spitting, and by burning the cloths or paper containing the discharges from his nose and mouth. Families may protect themselves by buying milk which is from cows known to be free from tuberculosis or which has been pasteurized, and by buying food which is protected from flies and dust in the stores.

*__Summary.__ The serious diseases which have been discussed thus far in this chapter are all believed to result from the attacks of bacteria,[1] which secrete and excrete poisons into the blood. These diseases and many others are contracted through contact with those suffering from the diseases, through food, water, and milk, and through the air. Science has discovered ways of stimulating the body to increase its resistance to various diseases. These artificial means include inoculation (1) with antitoxins, (2) with dead bacteria, (3) with weakened bacteria, (4) with weakened toxins, and (5) with a mixture of a toxin and its antitoxin. By such means as these not only can practically complete immunity be had to such diseases as smallpox, typhoid fever, and diphtheria, but also the chances of recovery of people suffering from certain diseases can be greatly increased.

State of New York Department of Health

Fig. 295. What are the advantages of having a thorough physical examination annually?

The number of cases and the death rate are steadily decreasing for most of the deadly bacterial diseases. This improvement has been brought about through (1) better sanitation, (2) more complete knowledge of the nature of the diseases, (3) better care of patients, (4) wider use of methods of prevention, and (5) wider use of inoculation. These diseases can be all but eliminated if people will pass and enforce laws which physicians and boards of health advise as necessary.

Self-test on Problem XXIII–B. 1. Less than fifty years ago tuberculosis was the *most* deadly of all diseases.

2. *Tuberculosis* may attack any one of several organs or parts of the body.

3. *Some* people are born with tuberculosis.

[1] It is not yet certainly known that smallpox is caused by a bacterium.

4. State four ways in which tuberculosis is spread.

5. Tuberculosis is usually contracted when one is *an adult.*

6. One *may contract* tuberculosis by handling objects which a tuberculosis patient has handled.

Problem XXIII–C · How does Science Combat Some of the Most Serious Diseases Caused by Protozoa?

Diseases caused by Protozoa. Among the most deadly diseases are some which are due, not to bacteria, but to Protozoa. Such diseases are more common in the tropics. For example, though many people in the temperate zones are infected with Protozoa, we seldom hear of the tropical dysentery which is caused by a species of *Amœba*; of skin ulcers caused by another genus of Protozoa; or of the sleeping sickness which is caused by still another. We may, however, be altogether too familiar with malaria, and we may also have had some first-hand experience with yellow fever.

Malaria. Malaria of several forms occurs in most parts of the tropical and semitropical regions of the world. It is more deadly in the tropics than in the temperate regions; yet it is a very serious disease wherever it is found. It is estimated that in India alone malaria is responsible for more than a million deaths per year. Of the European countries Italy especially has suffered. And in the South and the Middle West in the United States, malaria has been a serious disease for the past fifty or more years.

The name *malaria* comes from two Italian words meaning "bad air." The disease got this name because it was thought to be caused by swamp air. In this country it has gone under various names, such as "ague," "fever and ague," and "chills and fever." It is now known to be caused by a protozoan which during part of its life is a parasite in a certain genus of mosquito (*Anopheles*) and during the rest of its life is a parasite in human beings or some of the higher animals. The malarial parasite can live in only one kind of mosquito (Fig. 296).

If a mosquito of this genus sucks the blood of a person or animal suffering with malaria, it draws into its digestive system some of the parasites. In the mosquito's body they undergo several changes. Male and female cells join in the mosquito's stomach,

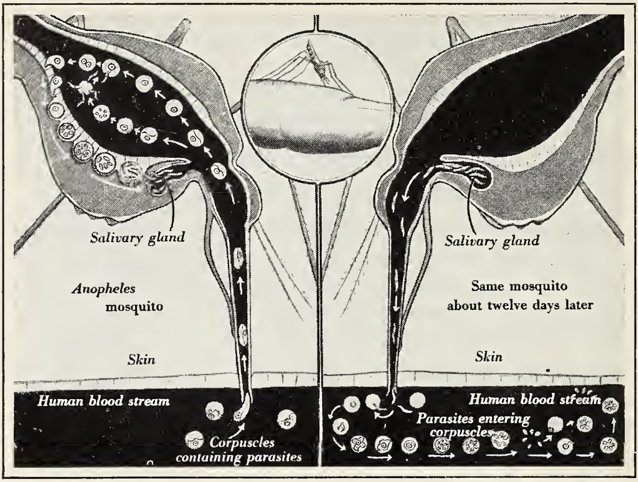


FIG. 296. The life history of the malarial parasite. Can you explain these diagrams? (See text)

forming fertilized cells. These bore into the stomach walls and form cysts. After undergoing further changes, these cysts divide into thousands of spores. These escape from the cysts and enter the blood stream, which carries them to all parts of the mosquito's body. They infect the salivary glands especially. About twelve days are required for all these changes to take place in the body of the mosquito. The parasites are now ready to complete their life cycle in the body of man or in the bodies of certain other animals.

When the mosquito bites a man, a horse, or a cow, the spores are transferred to the blood stream of the new host. They enter some of the red corpuscles of the blood, upon which they feed. There they undergo changes as a result of which from six to sixteen spores are formed for each original spore. The time required for these changes is twenty-four, forty-eight, or seventy-two hours, depending upon which type of malaria the mosquito carried.

Having destroyed the red corpuscles in which they were formed, the spores, with their secreted and excreted poisons, are liberated

into the blood stream. Each now enters a new red corpuscle. Some develop into the sex cells which, when taken into a mosquito's body, undergo the changes already described. The rest multiply rapidly in the corpuscles as before, releasing another host of spores. They may destroy more than half the red corpuscles, thus causing anemia. The chills and fever are believed to result from the sudden addition of toxin to the blood stream when the vast numbers of spores escape at the same time from the corpuscles into the blood.

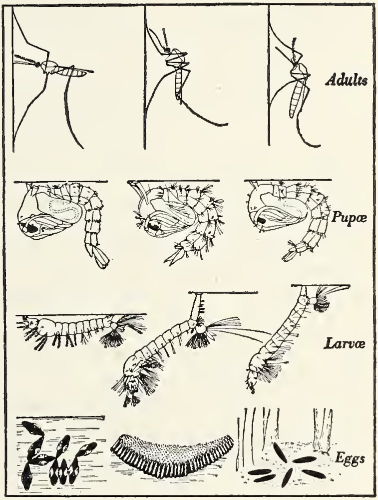


FIG. 297. Life histories of mosquitoes. Left, malarial mosquito (*Anopheles*); center, common mosquito; right, yellow-fever mosquito (*Aëdes*). How do they differ?

Quinine is a cure for malaria. It also prevents the disease to some extent, since it kills the parasites in the blood. However, malaria can be prevented more effectively in other ways. People should be protected with screens, so that no mosquitoes can reach them. Since these mosquitoes feed mostly at night, people should be especially careful in malarial regions to keep within screened houses during the night. The breeding places should if possible be drained. Cisterns should be screened. Oil or other substances which kill the larvæ (Fig. 297) should be poured upon puddles and swamps which cannot be drained. Goldfish and other top feeders, especially the gambusia of North Carolina, eat the larvæ and pupæ. So valuable is the gambusia for this purpose that recently these fish were transported to certain swamps in sections of Greece and Italy where malaria was especially prevalent. It has been found also that the presence of cattle and horses serves as a

protection to human beings, because the mosquitoes prefer their blood to that of man. Only the female mosquitoes bite. If the adult males eat anything at all, they feed only on plant juices.

Malaria is still a common and serious disease; yet through the use of the methods described in the preceding paragraph it is far less frequent now than formerly. In fact, in Rome, in Havana, and in the Panama Canal Zone, as well as in the Middle West and other parts of the United States, the number of cases has been reduced to a small fraction of the number thirty years ago.

Yellow fever. Yellow fever is a disease caused by a parasite, probably a protozoan. It is carried, as is the germ of malaria, by a certain genus of mosquito (*Aëdes*). Severe outbreaks of the disease have occurred in Louisiana, Mississippi, and Alabama, and occasional outbreaks in Philadelphia and Baltimore. Yellow fever is more deadly than malaria. From 12 to 80 per cent of those who contract the disease die from the attack. In Rio de Janeiro, in 1898, 94.5 per cent of those who contracted the disease died. The French, who in 1880 began the construction of a canal across the Isthmus of Panama, were forced to give up the attempt largely because of this deadly disease.

Yellow fever was traced to the mosquito as the result of extensive work by a group of American doctors who were appointed to study the disease in Havana in 1900, after the close of the Spanish-American War. After it had been definitely determined that the mosquito is the carrier of the disease, the same measures used in eliminating malaria were used for preventing yellow fever. Unlike the common mosquito, the ones that carry yellow fever breed only in fairly pure water, such as is found around dwellings. They will not breed in stagnant swamps.

Self-test on Problem XXIII–C. 1. Malaria, as well as __(?)__, is spread by (1) house flies; (2) mosquitoes; (3) ticks; (4) other people having the disease; (5) rats.

2. If all the insect carriers of these diseases could be killed, there would be *few* cases a hundred years hence.

3. Certain fish are proving valuable in reducing the carriers of the __(?)__ parasite.

4. The *insect* carrier of yellow fever breeds in *water*.

5. The parasite of __(?)__ feeds upon the *white* corpuscles of the blood.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Why is a horse a better animal to use in securing antitoxin serum than a guinea pig or a mouse?

2. What means of prevention of tuberculosis, other than those given on page 457, can you suggest?

3. Why is it important to recognize early the symptoms of such diseases as measles, diphtheria, and whooping cough?

Exercise on Scientific Method. 1. Making Inferences from Data. Certain tsetse flies are the carriers of African sleeping sickness. The insects are found in forests or underbrush, but seldom in cleared fields around dwellings. They are somewhat larger than a house fly and suck blood as a mosquito does. They are most troublesome during the hotter parts of the day. From these facts, state the plan one might make to prevent contracting African sleeping sickness.

2. Using Controls. How do the guinea pigs serve as controls in the making and testing of antitoxin serum?

Exercise on Scientific Method and Scientific Attitudes. The story of how the American doctors proved that yellow fever is caused by a germ carried by a certain genus of mosquito is one of the most interesting in the history of science. Dr. Walter Reed, a major in the United States army, was in charge of the commission, which included also Dr. James Carroll, Dr. Aristide Agramonte, and Dr. Jesse Lazear.

Dr. Reed first studied the known facts about how the disease was contracted. He found that those who nursed yellow-fever patients or were around those sick with the disease did not seem to take the disease. It seemed likely, therefore, that the disease was not spread from patient to well person in the same ways that diphtheria and other bacterial diseases are spread. But though it might not be passed in these ways, it still might be contracted from garments and bedding used by yellow-fever patients. To find out whether this was true, Dr. Reed called for volunteers to live in a hut by themselves and to wear the clothing worn by yellow-fever patients and to sleep in bedding in which they had died. None of these volunteers contracted the disease. He was therefore convinced that yellow fever could not be contracted in this way.

He had noted that some people living in the neighborhood where cases of yellow fever were first reported usually became sick with the disease two or three weeks after the first case. This suggested to him that there must be a carrier. The mosquito was suspected. To test this theory, Dr. Carroll purposely allowed one of the suspected mosquitoes to bite him. A private, Dean, allowed himself to be bitten by the same mosquito.

Both men became sick with yellow fever but recovered. When a little later one of the suspected mosquitoes lighted on Dr. Lazear's hand, he likewise allowed it to bite him. He took the disease and died.

These cases seemed to indicate that the carrier had been found. But further experiments were necessary before the commission could be sure. Dr. Reed then called for volunteers who would offer themselves for experiment. He had to use people because no animal was then known which was subject to yellow fever. Two men, Kissinger, a private in the army, and Moran, a clerk, knowing fully the dangers they braved, placed themselves at Dr. Reed's disposal. These men were kept by themselves for several weeks, where there was no danger that they would take yellow fever, and then they were allowed to be bitten by the suspected mosquitoes. Both took the disease, but both recovered. Dr. Reed and the other members of his commission were then satisfied that the mosquito was really the carrier of yellow fever.

What scientific attitudes (pp. 12–13) are illustrated by the various steps in the study of yellow fever? In what respects were Dr. Lazear, Private Dean, and Dr. Carroll controls? In what respect were Kissinger and Moran controls? Was it necessary that Kissinger and Moran should be kept by themselves for some time before they were allowed to be bitten by the mosquitoes? Explain. What further evidence would be necessary beyond that described here before the doctors could be *certain* that yellow fever was not passed directly from a sick person to another person? that it was not contracted from clothing and bedding used by patients? Did these experiments prove that the mosquito was the only possible carrier? Explain. Did Dr. Reed employ Koch's four steps in investigating this disease (p. 445)? If so, trace the four steps through Dr. Reed's investigation.

Special Reports. 1. Outline, in the same way as the story of yellow fever is outlined, the story of the determination of the cause of malaria. List examples of applications of scientific methods and scientific attitudes.

2. What are the nature, use, and value of the Dick test for scarlet fever? (Consult your family physician.)

3. What are the preparation, use, and value of tetanus serum? Explain why tetanus sometimes develops from a gunshot wound or from a wound caused by a rusty nail.

4. How was inoculation for smallpox practiced among the early Chinese? among the Turks of the early eighteenth century? What is the history of smallpox inoculation in Europe? What was Edward Jenner's contribution to the modern practice of vaccination? What is the early history of vaccination in this country?

Chapter XXIV · Improving Health through Applications of Biology

Questions this Chapter Answers

What are some health habits which are related to eating?
What are food sensitization and food poisoning?
What are food substitutes and adulterants?
What are the values and the defects of the pure food and drugs laws?
Are alcohol and tobacco harmful to digestion?
What is the narcotic danger?
How should one care for the teeth?
What are some health facts in relation to respiration?
How is artificial respiration administered?
Why are rest and sleep necessary to health?
What are some applications of first aid?
What are some health facts about the muscles and the bones?
How should one care for the eyes and the ears?
What is the hygiene[1] of the skin?

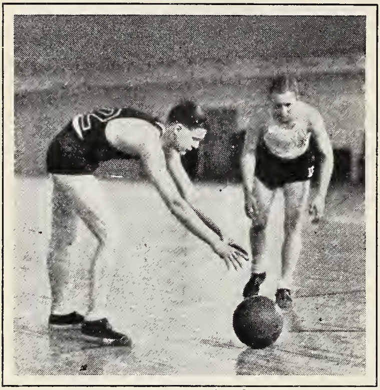
Problem XXIV–A · How are Hygiene and Health Related to Food Habits?

Health habits related to digestion. People differ from one another in so many ways that it is difficult to find scientific rules which apply to everybody. Nevertheless there are certain guides to health which physicians and health authorities believe may safely be followed generally. A number of these apply to digestion.

*Since the digestive functions cannot take place normally when one is too tired, it is usually desirable to rest for a short time before meals. One should also rest awhile after a meal, since violent exercise immediately after a meal interferes with digestion. One who takes daily exercise (Fig. 298) is less likely to have digestive troubles than one who takes little or no exercise. Fear and worry interfere with normal digestion. Meals should therefore be pleasant times during which only pleasant topics are discussed.

[1] *Hygiene* (hi'ji een): the application of rules of health.

Regularity in elimination of wastes is highly desirable. The number of daily eliminations differs with different persons, but regularity will enable one to avoid the serious dangers of constipation. One should avoid the use of medicines for constipation, except with the advice of one's physician, because their use may not remove the cause of the trouble. Also, if such medicines are used often, much harm may result, because in time the intestines may become unable to function without them.



© Culver Military Academy

Fig. 298. In what ways is exercise such as this beneficial?

Increasing or decreasing one's weight. There are some patent medicines which are advertised to enable the user to put on extra weight, and an enormously larger number that are sold as cures for obesity.[1] These, like all other patent medicines, advise the same treatment for everybody who has or thinks he has certain symptoms. The obesity cures fall into two classes, those for external use and those to be taken internally. The former, while possibly not harmful, are wholly worthless. The latter are usually harmful. Plenty of exercise, with moderate eating, is likely to keep one from becoming too fat. The American Medical Association, with offices in Chicago, Illinois, publishes a pamphlet dealing with dangerous and worthless obesity cures. It also publishes a book which gives advice, based on the best medical authority, on the question of what diets to follow to increase or decrease one's weight. In cases of underweight or overweight which do not respond to these instructions concerning diet, it is best to follow the advice of a physician rather than to experiment, since fatness or thinness may be due to one of a number of causes.

[1] *Obesity* (o bes'i ty): state of being very much too fat.

Food fads. There are fads, or styles, in eating, which some people follow just as they follow other styles. One of these is vegetarianism, the followers of which eat only vegetable foods. Another is the milk-diet fad, the followers of which take no food but milk. A third is the raw-food fad, the followers of which eat only raw fruits and vegetables. A fourth is the cooked-food fad. Yet another is the fantastic idea that it is harmful to eat proteins and carbohydrates at the same meal, although most of our commoner foods contain both proteins and carbohydrates. Still another, which was recently adopted by many young women who desired to become very slim, consists in eating considerably less than is necessary for health and proper development. This starvation fad results in serious dangers. It may, for example, reduce the resistance of the body to a point where the person may contract tuberculosis or some other dangerous disease.

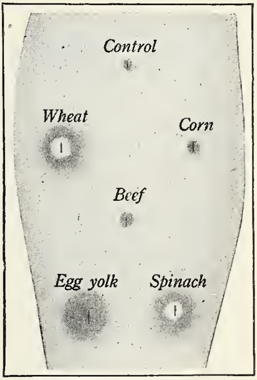


FIG. 299. Skin tests for food sensitization.[1] This person is sensitized to wheat, spinach, and egg yolk. How does the "control" enable us to know this?

None of these fads is based upon scientific evidence of values, and all should be avoided. The best plan is to eat moderately a balanced diet consisting of a wide variety of animal and vegetable foods. Every day's diet should contain energy foods to supply carbohydrates, proteins, and fats, and fruits and green vegetables to provide vitamins and mineral salts.

Food sensitization and food poisoning. Some people have what are called idiosyncrasies in connection with certain foods; that is, certain foods make them ill by causing asthma, hives, eczema, or other illnesses. Sometimes the food which is causing the difficulty is easily discovered, but often it is not. One method used by physicians in discovering whether a patient is sensitized to certain foods is that of "skin tests" (Fig. 299). Tiny scratches are made in the skin of the forearm. Nothing is done to one of these scratches,

[1] Andress, Aldinger, and Goldberger's *Health Essentials*. Ginn and Company.

the control, but a tiny bit of each of a number of powdered foods is gently rubbed into each of the remaining scratches. Sometimes the food samples are inserted beneath the skin with a hypodermic needle. After a few minutes each scratch which contains a food to which the patient is sensitized will swell much like a mosquito bite. Sensitization may often be overcome by eating a very small amount of the food causing the disturbance and by gradually, over a long period of time, increasing the amount eaten. But if a person finds that some food does not agree with him, the most sensible thing to do is to avoid that food, no matter how fond of it he may be.

Food substitutes and adulterants. A food substitute is a substance which can be secured in greater quantity and more cheaply than the food for which it is substituted. Thus oleomargarine or peanut butter is a substitute for butter. Potato flour and flours from barley, oats, and other grains are substitutes for wheat flour. The substitute often has a food value equal to that of the food for which it is substituted. In some cases, though not usually, it may have even more. During the World War the use of food substitutes was made especially necessary by the difficulty of feeding our own armies and people and at the same time of helping to supply food to our allies when so many of our men and women were withdrawn from normal food-producing industries to engage in various activities connected with the war.

Adulteration is quite different from food substitution. The purpose of food adulteration is dishonest, since it usually means putting in the place of part of the food some other substance which is less expensive to the producer. Thus milk is sometimes adulterated by taking from it some of the cream and adding water in its place, and sometimes by adding preservatives to keep the milk from souring. Coal-tar dyes are sometimes added to soft drinks to make them attractive. Sweetened grease is sometimes substituted for chocolate fillings. White sand is sometimes added to sugar. Sometimes the adulterants are merely harmless or less valuable as food than the substances to which they are added — for example, cereals in sausages. Frequently, however, the adulterant is harmful, as formaldehyde in milk, benzoate of soda in catchup or in sausages, or copper salts in canned vegetables to make them green.

***Pure food and drug laws.** Until 1906 there were no national laws in the United States to protect the buyer of canned goods

FEDERAL FOOD & DRUGS ACT

HERE ARE ITS POWERS AND LIMITATIONS REGARDING THE SALE OF "PATENT MEDICINES"

IT APPLIES ONLY TO PRODUCTS THAT ARE MADE IN ONE STATE AND SOLD IN ANOTHER (INTERSTATE COMMERCE).

IT PROHIBITS "FALSE OR MISLEADING" STATEMENTS (IN OR ON THE TRADE PACKAGE ONLY) REGARDING COMPOSITION AND SOURCE OF ORIGIN.

IT PROHIBITS "FALSE AND FRAUDULENT" STATEMENTS (IN OR ON THE TRADE PACKAGE ONLY) REGARDING CURATIVE EFFECTS.

IT REQUIRES THE MANUFACTURERS OF NOSTRUMS TO DECLARE (IN OR ON THE TRADE PACKAGE ONLY) THE PRESENCE AND AMOUNT OF ALCOHOL, MORPHINE, OPIUM, COCAINE, HEROIN, EUCAINE, CHLOROFORM, CANNABIS INDICA, CHLORAL HYDRATE AND ACETANILID AND THEIR DERIVATIVES.

IT DOES NOT APPLY TO PRODUCTS THAT ARE SOLD IN THE SAME STATE AS THAT IN WHICH THEY ARE MADE (INTRA-STATE COMMERCE).

IT DOES NOT PROHIBIT FALSE OR MISLEADING STATEMENTS IN NEWSPAPER ADVERTISEMENTS, CIRCULARS, WINDOW DISPLAYS, ETC.

IT DOES NOT PROHIBIT ANY KIND OF A LIE REGARDING CURATIVE EFFECTS IF THAT LIE IS TOLD ELSEWHERE THAN IN OR ON THE TRADE PACKAGE!

IT DOES NOT REQUIRE "PATENT MEDICINE" MAKERS TO DECLARE EVEN THE PRESENCE OF SUCH DEADLY POISONS AS PRUSSIC ACID, CARBOLIC ACID, ARSENIC, STRYCHNINE—NOR ANY OF SCORES OF OTHER DANGEROUS DRUGS!

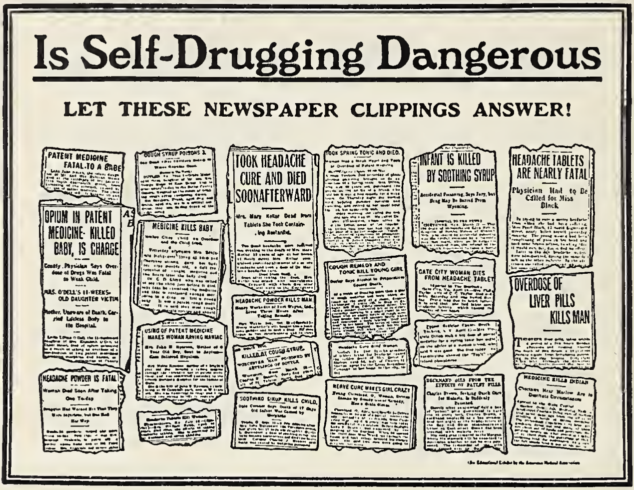
American Medical Association

FIG. 300. What further food and drug laws are needed?

from adulteration of foods. In 1906 Congress passed a law which compelled manufacturers of foods and drugs to limit the claims upon the label and to state the amounts of certain drugs contained in packages sold outside the state in which they were manufactured. Additional laws have since been passed both by Congress and by various state legislatures to protect the buyer further. More laws are needed, however (Fig. 300), because unfortunately the makers of foods are not compelled by law to tell the truth about their products when they advertise them in newspapers and magazines, on billboards, or over the radio.

The Consumers' Research, Washington, N. J., is an organization which operates without profit for the purpose of investigating foods and other commodities to determine quality and value. Anybody may secure this information by paying a small fee for membership in the organization.

Alcohol and digestion. Scientists have been unable to determine from the results of many experiments whether alcohol can



American Medical Association

Fig. 301. Why is self-drugging dangerous?

under any circumstances be considered a food. If so, it acts as an energy food when taken in very small quantities only. Even then it cannot be considered a desirable substitute for ordinary energy foods such as meat, milk, and potatoes. Scientists are agreed that when taken in larger quantities it cannot be considered a food, since its effects are always harmful.

Scientific evidence is conflicting with respect to the effects of alcohol upon the digestion. Most physicians and physiologists, however, would probably accept these statements: The more concentrated alcoholic drinks when taken before or during meals do not help the digestive processes, but rather hinder digestion. They decrease the quantity of enzymes which the various glands normally produce. Moreover, alcohol has a harmful effect upon the linings of the stomach and the intestines. The safest plan is to use alcohol only when it has been prescribed by a physician.

There are many so-called patent medicines which claim to be aids to digestion or cures for indigestion. Some of these, while harmless, are worthless (Fig. 301). Others, however, contain alcohol in harmful quantities and may present a serious possibility of acquiring the drink habit from their continued use.

Tobacco and digestion. Many people believe that tobacco serves as an antiseptic in the mouth. This belief does not have sufficient scientific foundation. Smoking does, moreover, have harmful effects upon digestion. Those who smoke are likely to suffer from coated tongue, bad taste in the mouth, irregular appetite, absence of taste, nausea, and a sensation of heaviness in the stomach. Also, heavy smoking is liable to result in injury to the liver and the pancreas.

Self-test on Problem XXIV–A. **1.** Cooking serves three major purposes: (1) to make food more palatable and more attractive; (2) to soften the fibers of tough meats and coarse-fibered vegetables and to break open starch cells; (3) __(?)__.

2. Patent medicines taken internally for digestive troubles *seldom* do harm and *usually* effect a cure.

3. Fatness is *always* due to eating too much.

4. Food fads are *usually* based upon scientific evidence.

5. Corn oil or cottonseed oil is *an adulterant of* olive oil.

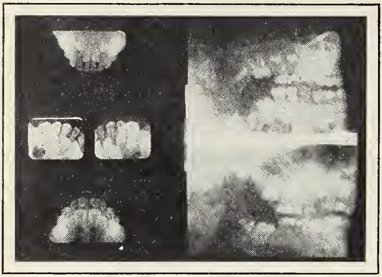
6. Peanut shells and sawdust added to breakfast foods are *adulterants.*

7. Alcohol and tobacco are believed by scientists to be *helpful* to digestion.

Problem XXIV–B · What are Some Important Considerations concerning the Hygiene of the Mouth?

The order in which the teeth appear. The first teeth to appear in a baby's mouth are the incisors (Fig. 302). These begin to push through the gums a few months after the child's birth. Other teeth grow behind the incisors from time to time, but in no definite order, until the first set of twenty deciduous teeth is entirely complete. When the child is about six years old, two molars grow back of the deciduous teeth, one on each side of each jaw. About six years later another molar grows behind each "six-year molar."

By the age of twelve or fourteen years the second set, or permanent teeth, have one by one taken the places of the deciduous teeth. But if the child takes good care of his teeth, most of this first set should serve for a number of years. The molars of the deciduous set are replaced with premolars in the permanent set. The last teeth to grow in are the third molars, or wisdom teeth. These generally come, if they come at all, when one is nearly grown. Sometimes one may be thirty years old or even older before they appear. The wisdom teeth are frequently small, not well formed, and of little use. They should, however, be kept if possible until the face has completed its development. Sometimes one or more of the wisdom teeth, as well as other teeth (Fig. 303), never appear at all. Sometimes there are extra teeth. If one is to have a full set of teeth, he will finally have thirty-two.



Dr. George R. Moore

Fig. 302. X ray of the jaws of a child. This photograph, taken at the age of six and one-half years, shows all the permanent tooth buds except those of the wisdom teeth. Can you locate the "six-year molars" and the second molars?

At about the age of five every child should have a complete X-ray examination of the mouth to determine whether all the permanent teeth are forming. In about 99 per cent of the cases all but the wisdom teeth can then be detected. These will be shown by an X-ray photograph taken at the age of eight or ten. In case the plates show that extra teeth are forming, these should have the attention of a dental[1] surgeon at once.

Care of the teeth. Bacteria multiply in particles of food left on or between the teeth. Some foods, especially the sweets, produce acids which attack the enamel of the teeth (Fig. 304). Besides affecting the teeth themselves the poisons produced by the bacteria of decay cause bad breath. Since some of the poisons are

[1] *Dental* (den'tl): pertaining to the teeth.

absorbed by the blood in the digestive organs, these poisons may cause a number of serious illnesses, such as neuritis and rheumatism. If the gums become infected these poisons may pass directly into the cells and blood vessels by osmosis.

*It is therefore a wise plan for every person to have his teeth

Dr. George R. Moore

FIG. 303. X ray showing a missing permanent tooth. *A*, no permanent tooth is forming under the deciduous molar; *B* (a photograph of the same part of another mouth), the permanent molar is forming in the normal way. Can you tell from the photographs whether any of these teeth have been filled?

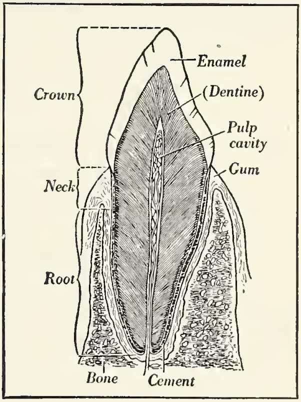
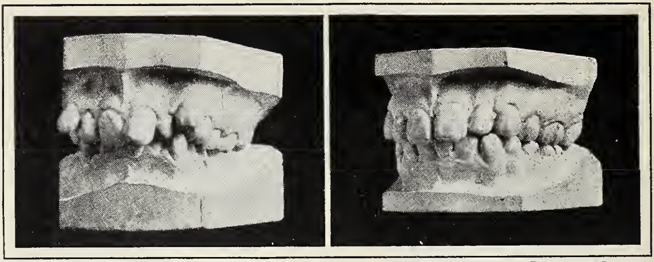


FIG. 304. Why is it desirable to brush thoroughly both the enamel and the gums?

examined by a competent dentist about every six months. If any teeth have begun to decay, the dentist will fill the cavities and stop the spread of the decay. If there are no cavities to fill, the dentist may give the teeth a thorough cleaning. If the teeth are crowded and uneven, effective chewing may be difficult and the features of the face may become disfigured. In such cases it is often desirable to seek the assistance of a specialist (called an orthodontist) to restore the teeth if possible to their correct positions (Fig. 305). This he is able to do without causing pain, by means both of exercises which he prescribes and of special braces which he designs and which gradually force the teeth into correct position.



Dr. George R. Moore

FIG. 305. Two models of the same jaw, before and after orthodontia. What advantages are gained from such treatment?

Mouth washes and dentifrices.[1] Extravagant claims are being made through the advertising in magazines and over the radio for antiseptic mouth washes which prevent decay or which give a pleasant breath, or for dentifrices which prevent decay and cure diseases of the gums. A mouth wash can have little value except to rinse away food particles after these have been loosened by brushing. Much is made by the advertisers of the fact that the mouth washes which they advertise kill germs in the mouth. Even if they do, little or no benefit is gained, because soon after the antiseptic is used there will be as many germs in the mouth as ever. A homemade mouth wash consisting of half a teaspoonful of common salt, with perhaps a little baking soda, dissolved in a glass of warm water will serve as well as anything of the sort which can be bought.

Teeth are made clean by thorough brushing and not by dentifrices. No dentifrice will cure or correct diseases of the gums (such as pyorrhea) or bleeding, spongy, or receding gums. No dentifrice serves practically as an antiseptic; none of them preserves the teeth. Dentifrices are made of such common things as precipitated chalk, soap, salt, baking soda, borax, magnesia, glycerin, alcohol, and water, together with flavoring and coloring matter. As good a dentifrice as any can be made of equal parts of soda and common table salt to which is added, if desired, a little

[1] *Dentifrice* (den'ti friss): a preparation for cleaning the teeth.

oil of peppermint or wintergreen for flavor. Teeth should be cleaned regularly night and morning, and the mouth should be rinsed thoroughly after each meal.

Self-test on Problem XXIV–B. 1. The normal number of deciduous teeth is __(?)__.

2. The normal number of permanent teeth is __(?)__.

3. The deciduous teeth should be *extracted* as *soon* as possible after the permanent teeth begin to grow in.

4. Select from the following list of practices in the care of the teeth the desirable ones: (1) visit the dentist about every six months; (2) use patent antiseptic mouth washes; (3) brush the teeth regularly twice a day; (4) use only the dentifrices which are advertised over the radio; (5) consult an orthodontist if one's teeth are irregular; (6) rinse the mouth after a meal; (7) have an X-ray photograph taken of the teeth when about five years old.

Problem XXIV–C · How are Hygiene and Health Related to Respiration?

Hygiene of respiration. If the respiratory system is normal and healthy, one breathes through the nose and not through the mouth. Persistent mouth breathing is an almost certain symptom that something is wrong with the breathing apparatus. The trouble may be due to adenoids (Fig. 226, p. 341), which are abnormal growths of certain tissues (lymphoid) in the rear of the cavity of the nose. Or it may be due to the fact that bones or tissues in the nose may have grown out of place in such a way as partly to close the passages. The results from any of these causes may be serious trouble, such as frequent colds, faulty development of the teeth and palate, and, in extreme cases, deafness. Such troubles may usually be avoided by having a thorough examination from time to time by a physician. In case of serious respiratory trouble a specialist in diseases of the ear, nose, and throat should be consulted.

Deep breathing. It used to be thought that everybody should learn to breathe as deeply as possible. Special breathing exercises were practiced for the purpose of increasing the capacity of the lungs. It is now no longer believed that such exercises are bene-

ficial. On the contrary, with some people — for example, those who are suffering from tuberculosis — such breathing exercises are liable to be harmful. If one is in good health he need not be concerned about his breathing, because he will naturally breathe the quantities of air he needs for his various activities. Cultivating a good posture will help to insure that one's breathing will be proper. One should avoid wearing tight clothing which prevents free and comfortable breathing.

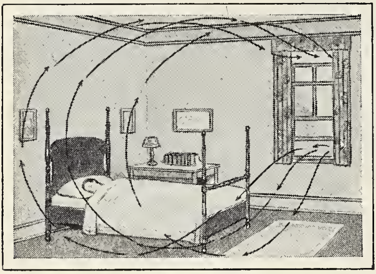


FIG. 306. Can you explain why the air currents move in the direction of the arrows? (If you cannot, look up the subject of ventilation in a textbook of general science or physics)

Tobacco and respiration. Some recent experiments indicate that the use of tobacco may result in real harm to the respiratory system. A study of more than six hundred men showed that smokers were more often ill with acute respiratory diseases than were nonsmokers. Those who inhale cigarette smoke are more liable to contract laryngitis, a disease of the larynx, than are those who do not. "Smoker's asthma," a disease which makes difficult the drawing of a full breath, may also result from excessive smoking. There is considerable evidence to prove that tobacco is harmful to young people. The student who smokes is in general less successful, both in athletics and in school work, than the one who does not.

Ventilation. Contrary to popular belief, the air contains a far greater percentage of oxygen than is needed for oxidation and the consequent release of energy within the body cells. Therefore ventilation is not usually needed in order to supply necessary oxygen or to remove the excess of carbon dioxide produced by respiration. In fact, one may breathe the same air over and over without injury and without discomfort, provided the air is kept circulating.

*The circulation of air through ventilation (Fig. 306) serves chiefly to reduce the quantity of water vapor in the air immediately

around the body. If the vapor content is high and if the air is still, not much sweat can evaporate because the air, especially that next the skin, soon becomes saturated. Therefore the body cannot then get rid of its surplus heat through evaporation of sweat. Ventilation does to some extent help to remove an excess of heat from the body surfaces by convection. Circulation of air through ventilation serves also to remove foul odors. These, however, are more likely to be unpleasant than to be harmful.

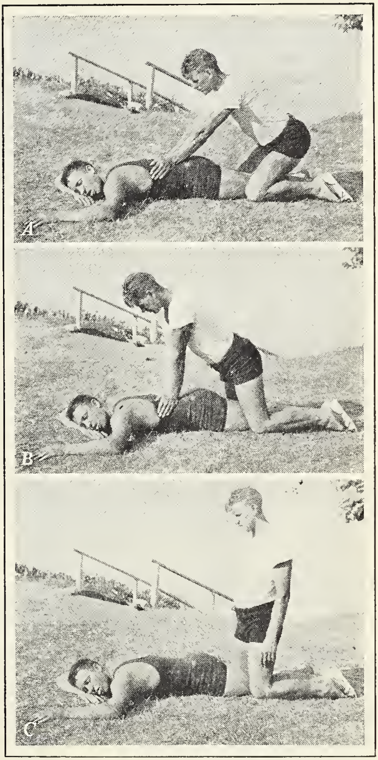


FIG. 307. The stages in artificial respiration. Special Report: What is the pulmotor and how does it operate? (Consult the local fire department)

* **Artificial respiration.** Artificial respiration is of great value not only in cases of drowning but also in cases in which people have been overcome by inhaling cooking gas or have suffered from a severe electric shock. The artificial respiration should be started *immediately. Every second counts.* Place the patient in the position shown in Fig. 307, *A*, with a rolled coat or sweater under the middle of the body. Lean steadily forward so that you exert a firm *but not too great* pressure upon the patient's body (Fig. 307, *B*). Sway backward, releasing the pressure (Fig. 307, *C*). Repeat this movement, swaying back-

ward and forward on your knees about twelve times per minute. It is especially important that the motions be kept slow, smooth, and regular. In order to insure this it is well to count slowly, "one, two, three" while the breath is being forced out of the lungs, and "four, five" while the breath is entering, or to say slowly "Force the bad air out" while the pressure is being exerted, and "Let the good air in" when the pressure is relaxed. Artificial respiration should be continued for four hours before giving up.

When the patient shows sign of life, *it is especially important* to keep him lying *face down* until he has recovered sufficiently to get up without help.

Self-test on Problem XXIV–C. **1.** A normal person breathes through his *mouth.*

2. Taking breathing exercises to increase the lung capacity is now considered *desirable.*

3. There is considerable scientific evidence which tends to prove that the use of tobacco is *harmful* to the respiratory system.

4. The chief purpose of ventilation is to __(?)__.

5. The higher the humidity the *easier* it is to become cool.

6. In cases of drowning, artificial respiration should be continued for at least *an hour.*

Problem XXIV–D · What are Some Further Considerations in Relation to Hygiene and Health?

Rest and sleep necessary to health. Fatigue results from any kind of work which is continued over too long a period. Active muscles are constantly using energy. Protoplasm is constantly breaking down, producing waste products which to some extent serve as toxins or poisons. As these increase in quantity they interfere more and more with the muscular action. During the period of activity these waste products are produced more rapidly than they can be removed. Decreased activity during rest or sleep is necessary to permit the removal of the waste products and the replacement of protoplasm.

The amounts of rest and sleep which different people require vary greatly. Napoleon and Edison were said to need far less than

the average person. One should find out how much sleep he requires to feel well and to do his work most effectively. He should then make sure of getting this required amount of sleep. For the average adult the number of hours is about eight. For the growing boy and girl it is usually about nine hours.

Marion Hill

FIG. 308. How many advantages which are derived from exercise in the fresh air can you name?

Somebody has said, "We become tired of work more often than we become tired by working." This statement means that a frequent change of work is desirable as a means of reducing fatigue. Variety of activity employs new sets of neurons and muscles, thus giving tired cells a chance to recover their normal state. Variety in itself gives pleasure. Moreover, great value is derived from exercise as a means of recreation (Fig. 308). It should be kept in mind, however, that when one is greatly fatigued the activity even of play will only add to the fatigue. In such cases, only rest and sleep will serve.

Fainting. When for any cause the brain receives an insufficient supply of blood, fainting is likely to result. The patient should be placed on his back with his head lower than the rest of his body, so that the blood will flow quickly into the head. The clothing should be loosened, and the space about the patient should be kept clear of people, so that he may have plenty of fresh air. Cold water sprinkled on the face, but not thrown in quantities, sometimes helps to revive the patient. Smelling salts and household ammonia on a handkerchief held near but not touching the nose may likewise help. After the patient regains consciousness keep him lying down for a time.

Cuts and bruises. Minor cuts and scratches should be sterilized with tincture of iodine or a 2 per cent solution of mercurochrome. Minor cuts and wounds should be bandaged with sterilized band-

ages, but not too tightly. Bleeding can usually be stopped in a minor cut or wound by elevating the member and applying pressure directly on the wound. In case an artery or vein is severed pressure applied with the fingers above and below the wound should first be tried. If this treatment does not stop the blood flow, a tourniquet (Fig. 309) should be applied thus: A cloth should be tied around the member. A stick should then be inserted under the cloth and twisted until the cloth is sufficiently tight to stop the bleeding. If an artery has been severed the blood will spurt in pulsations corresponding to the heart beat. In such a case the tourniquet should be applied between the cut and the heart. If a vein has been severed the blood will flow quietly. The tourniquet should then be applied on the side of the wound away from the heart. After ten or fifteen minutes the tourniquet should be cautiously loosened, permitting the blood to flow into the tissues freely, even though bleeding begins again. Unless this is done serious results may follow, since, in order to heal, the tissues must be plentifully nourished by the blood stream. After the blood has flowed for a few minutes the tourniquet may be restored if the bleeding still continues. Keep the wound bandaged; and do not change the bandage often, since by so doing you are almost certain to start the bleeding again.

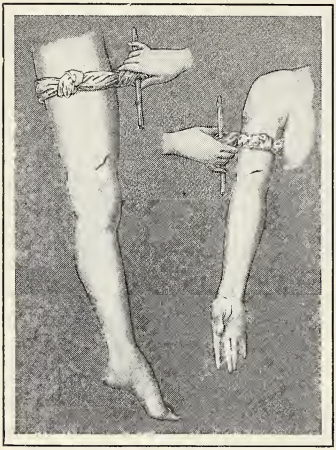


FIG. 309. These tourniquets are correctly placed for severed arteries. Where should they be placed for severed veins? Can you see any survival value in the fact that in general arteries lie deeper than veins?

In bruises the tissues are injured so that the blood flows out of the capillaries under the skin, causing the "black and blue" appearance. Applications of very warm or cold water will hasten healing.

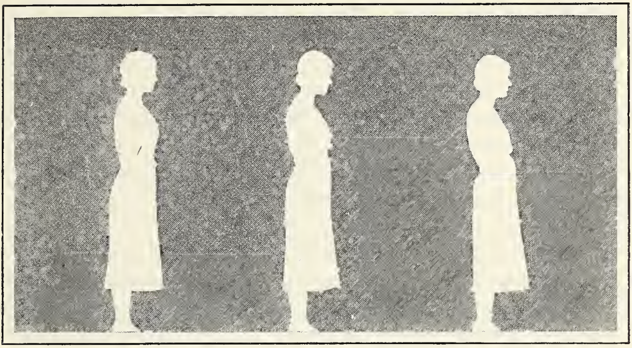


FIG. 310. The best exercise one can take to improve posture consists simply of assuming correct standing, sitting, and walking postures many times a day. Explain. Which of these three poses illustrates correct standing posture?

Hygiene of the bones and muscles. The muscles are attached to the bones and serve as levers to move them. The legs, arms, feet, and hands are controlled by two sets of muscles, the extensor muscles and the flexor muscles. The extensor muscles, as the name implies, extend the member; the flexor muscles pull it back. The extensor muscles are relaxed while the flexor muscles are contracted, and vice versa. Muscles should be developed through exercises which are not too violent and which are continued regularly and over a considerable period of time.

*The bones and muscles make up a large part of the body and by their position exert great influence on the internal organs. When one becomes careless of his sitting and standing positions and permits bad posture habits to develop he may permanently and seriously injure his body. Especially is it true that young people need to form good posture habits (Fig. 310); for it is while the bones include much cartilage that we give them the form that they are likely to keep throughout life. Bending over too long at a time to write or do other close work and holding the head forward in standing and walking may cause round shoulders. Sitting at a desk with one arm held on the desk to write while the other rests in the lap may tend to cause curvature of the spine.

Hygiene of the feet. Some of the serious foot troubles are caused by straining the foot muscles and leg muscles. Such strains may be due to too much walking or standing or to ill-fitting shoes. Weakening of the muscles and tendons may cause fallen arches; that is, the bones of the arch of the foot may sag, causing great discomfort. One should be careful always to select shoes which are large enough to be comfortable and which have low heels. In walking, one should point the toes straight ahead, to prevent muscular strain.

Corns and blisters are caused by the rubbing of ill-fitting shoes. A broken blister may become infected and hence should be painted with some antiseptic — for example, mercurochrome or tincture of iodine — and should be bandaged to prevent the entrance of dirt and germs.

The effects of alcohol upon muscular work. Extensive experiments have given results which show that even a little alcohol decreases the amount of effective work which one can accomplish. One may even work harder after taking some alcoholic drink, — that is, he may use up considerably more energy in attempting to do the same task, — but he will accomplish less than at times when he has taken no alcohol. Moreover, fatigue is not removed by alcohol. The belief that it is, is due to the fact that alcohol affects the higher nerve centers and therefore interferes with one's judgment.

* **Hygiene of special sense organs.** *The eyes.* If the eyes are to serve well during one's entire lifetime it is necessary that they always have the best possible care. Avoid straining the eyes. Do not read or sew in a flickering, dim, or fading light. Do not read when there is a glare upon the paper. Wear amber-colored or blue glasses while driving, especially if the sunshine is bright.

*The safest rule to follow in case of real or suspected trouble with the eyes is to consult a specialist in eye diseases. Dizziness, headache, and sometimes indigestion may be symptoms of defective eyesight. Moreover, many people suffer more or less from the need of glasses without knowing that they do. It is prudent, therefore, especially for young people, to consult an eye specialist every year or so, even though no definite symptoms of trouble have appeared.

Rubbing an injured or inflamed eye is dangerous, since such practice is liable to increase the irritation.[1] Cinders or dust can sometimes be removed from the eye by using a corner of a clean handkerchief, by pulling the upper lid over the lower one and then winking rapidly, or by bathing the eye in warm water containing boric acid. The eye is so delicate and complex, however, that only a specialist should attempt any but simple first aid.

* *The ears.* Deafness may result from a number of causes. These include injury to the eardrum and infections of the middle ear, due often to diseased tonsils and to adenoids. Earache is often a symptom of such an infection. If the pus produced cannot escape through the tube to the throat (Eustachian tube), it may burst the eardrum. In case of disturbing symptoms in the ear, therefore, it is always safest to consult a physician — if possible, an ear specialist. Do not thrust an ear spoon, a needle, or any other sharp instrument into the ear because in so doing there is danger of injuring the eardrum or the membrane lining the canal. A shout directly in the ear or a blow on the ear has been known to produce deafness by bursting the eardrum. Do not blow the nose violently or hold the nostrils while blowing the nose. By so doing, there is danger of spreading the infection by forcing harmful bacteria into the middle ear. Do not use nose drops or ear drops except with a physician's approval of the kind used and of the way in which they are used. The person who has been made immune to scarlet fever and diphtheria has decreased his chances of the ear infections which these diseases are liable to produce. Many patent medicines and "eardrums" are on sale which are claimed by their makers to relieve ear troubles and deafness, but they will do no good and may do serious harm. For those who have defective hearing, however, there are on the market several electrical aids to hearing that are of value.[2]

Hygiene of the skin. It is stated that the people of a certain small nation of Asia never bathe. They believe it is sinful to

[1] *Irritation* (ir ri ta'shun): that which excites unpleasantly or inflames.

[2] Some of these hearing devices, however, are advertised under claims that go far beyond the facts. Much valuable practical information for those who are deaf may be obtained from the American Federation of Organizations for the Hard of Hearing, 1537 Thirty-fifth Street, N.W., Washington, D.C.

Fig. 311. How many advantages of surf bathing can you list?

bathe, because they think dirt is given to them by the Creator as a covering and protection for their bodies. These people frequently have foul sores and loathsome skin diseases upon their filthy bodies as a result of not keeping clean.

If there were no reason for bathing other than the desire to keep clean, that would be a sufficient excuse for frequent baths. But there are other reasons (Fig. 311). There are oil glands in the skin in addition to the sweat glands. They pour upon the surface of the skin an oily substance part of which evaporates, leaving a solid film. This film closes the mouths of the sweat glands and thus prevents their functioning. One should therefore bathe frequently in order to keep the pores open.

Sunshine and sunburn. The effects of sunshine on the skin are healthful and stimulating. But the time of exposure to the sun's rays should not be too long. One should avoid severe sunburn, which is always painful and may be very serious. A "healthy tan" is desirable for some people, but it has not been proved that too deep a tan is beneficial. Getting tanned is a fad which, like all other fads, may be overdone. There are, moreover, certain people (called heliophobes) who cannot become tanned. Instead they continue to sunburn. Such people should not try to get a coat of tan and should remain exposed to the sunshine for brief

periods only. Sweet cream is soothing and healing to sunburn, but a bad case of sunburn should be treated by a physician, like any other serious burn.

Within the last few years many types of electric lamps have been manufactured and sold under the claim that they provide "artificial sunlight" in the home. The Council on Physical Therapy of the American Medical Association has made extensive investigations of these lamps. It announces that a few, if properly used, (1) give benefit in cases of rickets, a disease of childhood which is caused by improper diet and which results in a softening and deforming of the bones; and (2) aid in developing sound bones and teeth. The council, however, does not accept the claims that the use of such lamps "increases the tone of the tissues or of the body as a whole, stimulates metabolism, acts as a tonic, increases mental activity, or tends to prevent colds." The American Medical Association furnishes free information concerning the sun lamps which it approves.

Narcotics. The term *drug addict* is fairly familiar and is commonly used to indicate a person who has formed the terrible habit of taking morphine, opium, cocaine, heroin, or hashish (*Cannabis indica*, or Indian hemp). These drugs are habit-forming, as are also alpha-eucaine, beta-eucaine, chloral hydrate, and acetanilid. Some of these drugs have a valuable use in medicine and surgery since they relieve pain and to some extent stop its effects upon the system. All, however, are to some extent poisonous to protoplasm since they prevent cells, especially those of the nervous system, from carrying on their normal functions.

Few people would deliberately form the habit of taking any of these terrible narcotics. Yet it is possible to acquire drug habits through taking certain so-called patent medicines (Fig. 312). A considerable number of secret remedies, sold widely in drug stores and advertised to relieve asthma, catarrh, pneumonia, coughs, croup, tuberculosis, and even eye troubles, are known to contain small quantities of one or more of these narcotics: morphine, hashish, opium, heroin. The Food and Drugs Act of 1906 and the Harrison Narcotic Act passed a few years later helped to reduce the use of narcotics in patent medicines. It will be seen from Fig. 300, p. 469, however, that much still remains to be done.

A particularly dangerous group of patent medicines are those that are sold for the relief of pain and particularly as cures for

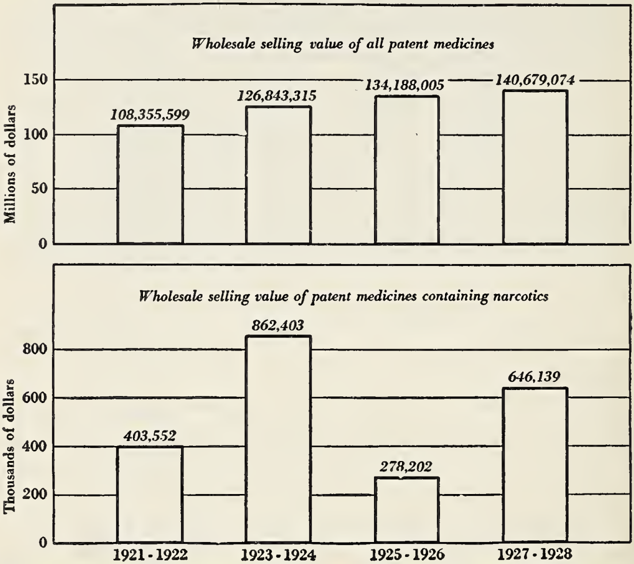


FIG. 312. The upper graph shows the wholesale values of all patent medicines for the years given. The lower graph shows the wholesale values of patent medicines containing narcotics. Did the money spent on patent medicines between 1921 and 1928 increase or decrease?[1]

headaches.[2] Most of these contain some of the coal-tar drugs that not only become habit-forming when used over a long period but also depress the heart and disorganize the red blood corpuscles.

Self-test on Problem XXIV–D. 1. A person who has fainted should be placed with his *head* higher than his *feet*.

[1] Figures from "Narcotics in Patent Medicines," by Arthur J. Cramp, in the *Journal of the American Medical Association*, June 6, 1931.

[2] The American Medical Association, through its Bureau of Investigation, publishes a large amount of material concerning patent medicines and stands ready to answer any questions on the "patent-medicine problem" that may be submitted to it.

2. A tourniquet should not be kept tightly bound for more than *an hour.*

3. Good posture is of importance to *health.*

4. The use of alcohol makes it *easier* to do effective muscular work.

5. It is *sometimes* desirable to use patent medicines for eye and ear troubles.

6. One can obtain sound advice in regard to sun lamps from the __(?)__ Association.

7. Getting a deep tan is *healthful* to *all* people.

8. One may acquire a *drug habit* from the use of certain patent medicines.

9. *No* new laws are needed for the control of the use of narcotics.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Can you name other food substitutes and adulterants than those named in this chapter?

2. In a certain meat market was a sign which read: "Our sausages contain only the purest benzoate of soda. Try them." Was the proprietor complying with the letter and the spirit of the pure food laws?

3. Good habits of posture are acquired in the same way as any other habits. One must first have a desire to improve his posture. What further steps must one follow if the habit is to become permanent?

4. Why is it a bad habit to sit slumped down in a chair with only the small of the back touching the chair back?

5. It is not desirable to use adhesive tape or "new skin" directly over a wound. Explain.

6. Why is pus less liable to be present in cuts and scratches that have been painted with iodine?

Special Report. What patent medicines now on sale in drug stores contain habit-forming drugs? Write for information to the American Medical Association, Chicago, Illinois.

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Unit VII · *Improving Methods of Using and Conserving Energy*

PROBLEMS DISCUSSED IN THIS UNIT

If one were to be able to revisit the earth a hundred million years hence, it is by no means certain that he would find any living things. Even if plants and animals should still exist, there might not be any surviving human beings. Many plants and animals have become extinct in the past; it would be possible for the same fate to overtake man in the future. But if man should be beaten in the struggle for existence by other more successful plants and animals, his elimination would probably be due at least in part to his failure to make proper use of biological knowledge. In order to continue to survive he must secure and maintain control of sufficient supplies of energy for all his present and future needs. To succeed in doing this he must produce and conserve useful plants and animals and must control destructive or harmful forms.

This unit deals with these major problems of conservation:

How may desirable wild life be conserved?

What provisions are being made by the government for the conservation of wild life?

How may cultivated plants and domestic animals be protected from their many enemies?

Chapter XXV · Control and Conservation of Cultivated Plants and Domestic Animals

Questions this Chapter Answers

What are the sources of soil?
How does the nature of the soil determine the nature of the plants?
What are some important facts about soil bacteria?
How are irrigation and dry farming used in growing crops in arid soils?
How does the insect problem affect agriculture?
How does man try to control insect pests?
How successful is man in his war against the insects which attack crops and domestic animals?
How does man fight the fungi which compete with him for energy?

Problem XXV–A · How do Men Use and Conserve Soil Values?

Importance of knowledge of the soil. Since man first began to farm, he has had to learn how plants grow. At first he used only the most fertile and well-watered land. Now he has reclaimed deserts by irrigation and has drained marshes. He adds fertilizers to poor soils. He cultivates the soil carefully to keep down weeds and to conserve moisture. He practices rotation of crops to restore necessary materials to the soil and to control plant diseases.

Sources of soil. According to the theory of the earth's formation which is now accepted by most scientists, there was a time billions of years ago when there was no soil. The earth's surface is thought to have been rocky and porous at that time. It is believed to have been composed of many separate pieces of rock and compounds of metals. These lay scattered about just as they fell as meteorites[1] and meteoric dust. This period was of course ages before there were any living things upon the earth, and even before

[1] *Meteorite* (me'te or ite): a mass of rock or metal which falls upon the earth's surface from space. *Meteoric* (me te or'ik): having to do with meteors and meteorites.

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FIG. 313. An imaginary picture of the earth before life. Which conditions shown in this picture are necessary for life and which might make life impossible?

there was water. There may have been no atmosphere at that time. In this state rocks could not change in their composition. They could change in size only by breaking up as they were suddenly heated or cooled when they were struck by falling meteorites or when they were broken apart by gravity.

Only after the earth had finally, by the addition of meteorites, grown sufficiently to hold an atmosphere was it possible for weathering,[1] or the formation of soil, to begin (Fig. 313). The oxygen in the air and in pores of the rocks combined with various substances in the rocks, thus changing them into different compounds. The water, falling as rain and running from higher to lower ground, carried with it the particles which had been weathered. This exposed the rock to further weathering. When water froze in the crevices of rock, it expanded and broke the rock. At the same time running water and slow-moving glaciers eroded or crushed some of the rock along their courses.

Slowly, during the course of millions of years, all but the steepest slopes and the tops of mountains became covered with soil. This soil was deposited in lower places by wind, running water, and moving ice. When finally plants and animals appeared on the earth, they also made important changes in the nature of soil. They gave off chemical compounds which combined with sub-

[1] *Weathering* (weth′er ing): the process of breaking up rock and changing it into soil.

FIG. 314. How are these plants adding to the soil?

stances in the soil. Their dead bodies added organic matter. By their various activities plants further broke, added to, and changed the nature of the ground (Fig. 314).

Kinds of soil. There are many kinds of soil, depending upon the kinds of rocks which decayed or were broken up to produce them. Soils are usually classified in terms of the size of the particles composing them. These particles range in size from that of small stones to microscopic particles of clay. Soil may consist largely of stone, gravel, sand, silt, and clay. Mixed with the particles of decayed rock is humus, that is, decaying organic matter.

Experiment 83. Of what is ordinary soil composed? Take a handful of soil and examine it with a strong hand lens. How many different kinds of substances do you find? Does the soil contain humus?

Dependence of plants on soil. If there were no soil, there could be no life of any sort on the earth. There could be no plants, and hence there could be no animals. Even fresh-water and ocean plants could not live without the materials which are dissolved from the soil. Land plants depend upon the soil for (1) anchorage,[1] (2) water, and (3) certain substances needed as building

[1] *Anchorage* (an'ker aj): a place used for or fit for a holdfast, or some kind of attachment.

materials. To be fertile, soil must contain compounds of the elements potassium, calcium, phosphorus, magnesium, sulfur, nitrogen, and iron. Compounds of other elements also are needed for certain plants. These compounds must be soluble in the soil water, so that they can be taken up by the plant roots by osmosis. Whenever fertilizer is put into the soil it is for the purpose of supplying some necessary substance which is lacking.

Fig. 315. The lady's-slipper will die if transplanted to ordinary soil. Can you suggest a reason? This plant is being exterminated by excessive picking. Special Report: What native wild flowers are especially in need of conservation. (Consult the Wild Flower Preservation Society, Washington, D.C.)

The nature of the soil determines the kinds of plants which will grow in it. The best soils for agriculture are loams, which consist of various mixtures of sand, clay, and humus. Certain plants, such as the hardy weeds, can grow in a wide variety of soils. Others, such as some of the choicest flowering plants, require very special soils. Certain garden crops, such as onions and celery, thrive best in a heavy soil called muck, which is very rich in humus. Other crops, such as peanuts and potatoes, are better suited to sandy soil. Poorly drained soil is likely to become acid because the carbon dioxide given off by plant roots dissolves in the soil water and forms carbonic acid. Certain plants, such as clover, will not thrive in acid soil; others, such as some of the coarse grasses, grow best in such soil. Some of the most beautiful flowering plants (Fig. 315) will grow only in very rich humus.

* **Soil bacteria.** Wherever there is abundant organic matter decaying in the soil, there are also many bacteria. Several kinds of bacteria do useful work in enriching the soil. Were it not for

the activities of these bacteria, life on the earth would cease. The bacteria of decay attack dead animal and plant material and animal wastes. They are able to change the complex organic compounds into a nitrogen compound, ammonia, and also into simple compounds of sulfur and phosphorus. Other bacteria are able to convert the ammonia resulting from the processes of decay into other simple nitrogen compounds. These compounds in turn are converted by still other bacteria into nitrates which can be used by plants in making proteins for their uses.

Experiment 84. Are there special growths upon the roots of clover or alfalfa which are not on the roots of dandelion or lawn grass? Carefully remove several clover or alfalfa plants, together with several dandelion plants or clumps of grass. Wash all the soil from the roots and examine them carefully. In a few sentences or by means of sketches describe the differences.

*Still other kinds of bacteria enter the roots of leguminous, or pod-bearing, plants such as beans, peas, clover, and alfalfa. These bacteria gain entrance through the root hairs. They remain in the outer layers of root cells, where the plant by building thicker walls of cells around the bacteria develops round growths called nodules or tubercles. These nodules on the plant roots protect the bacteria. The bacteria are able to take from the air in the surrounding soil free nitrogen, which plants and animals cannot use, and to convert it into simple, soluble nitrogen compounds which plants can use. The plant thrives better because of the nitrogen compounds made by the bacteria. When the plant dies and its roots decay, any resulting nitrogen compounds remain as fertilizer in the soil. In order to restore nitrogen compounds to depleted soils, therefore, farmers often grow leguminous crops and plow them under. Even when crops of beans, peas, alfalfa, or clover are removed their roots enrich the soil. When grain crops and leguminous crops are thus grown in successive seasons the process is called rotation of crops.

Each of the bacteria described in the paragraphs above has an important relation to the nitrogen cycle. The *nitrogen cycle* involves (1) the use of nitrogen compounds, as proteins, by plants and animals; (2) the building of protoplasm; (3) the decay of dead plant and animal bodies, releasing nitrogen compounds to

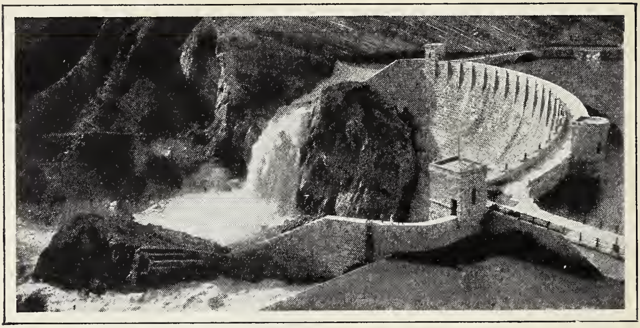


Fig. 316. The Roosevelt Dam in Arizona. How is this dam related to biology?

the soil or free nitrogen to the air; (4) the changing, by bacterial action, of these compounds to nitrates or of the free nitrogen to soluble compounds, which the plant can use to make proteins.

Irrigation and dry farming. One usually thinks of a desert as a sandy waste on which little life can exist. Yet many desert regions have excellent soil. If given an adequate water supply, these soils will produce abundant crops of cultivated plants and will grow plants that can live under the severe conditions. Many of the arid regions of the West have been made productive crop lands through irrigation. In recent years many huge dams have been built to secure the water necessary for extensive irrigation projects (Fig. 316).

In many places dry farming has been found to be a better and more economical procedure than irrigation. Dry farming is based on the fact that if the surface soil is kept in a fine, loose condition but little water will escape from it. Accordingly the ground is cultivated after every rain to keep it in condition so that it will absorb water like a sponge and to prevent evaporation of water from its lower layers. Thus a sufficient quantity of water is stored in the soil to make possible the production of a crop every other year.

Modern scientific agriculture has developed to such an extent that a surplus of food can now be produced. In earlier days men constantly sought new areas into which to extend their agricultural

efforts. Clearing and draining new lands, reclaiming arid lands for use in irrigation and dry-farming projects, continued farming of older agricultural areas, and applications of scientific farming now make possible the production of an abundance of food.

Self-test on Problem XXV–A. **1.** In the earliest ages of the earth the surface was covered with *fertile* soil.

2. If the earth had never had an atmosphere, it could have had *little* soil.

3. Soil is constantly being carried from the *valleys* to the *hills*.

4. *No* soil particles are microscopic.

5. There would be *few* fish in the oceans if there had never been any soil on the earth.

6. The practice of planting alfalfa in a field one year and wheat the next is an example of __(?)__.

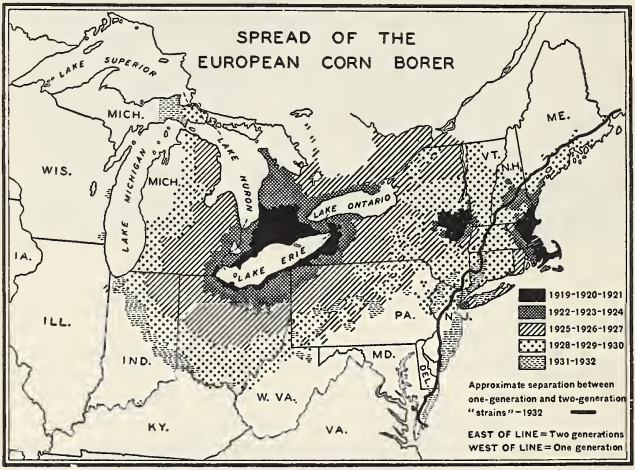
7. Many desert regions have been made to produce good crops by dry farming and __(?)__.

Problem XXV–B · How does Man Protect his Crops against Insect Pests?

Agricultural production and the insect problem. Insects carry on a varied war of conquest against men. (1) They attack growing crops of grain, vegetables, and fruit; (2) they feed on stored products; (3) they may produce disease directly in domestic animals or indirectly by carrying disease organisms from one animal to another; (4) they attack orchard and forest trees; and (5) in other ways they injure men directly or indirectly. The annual loss due to insect pests in the United States amounts to over a billion and a half dollars. Entomologists estimate that insects destroy one tenth of all our farm crops. Many of us who live in cities may think that the activities of insects do not concern us. Yet for the damage they do we pay increased prices for food and clothing.

It is in their feeding activities that insects do their chief damage to our crops. The varied food habits of different species of pests subject plants to attack in all their stages and in all their parts. The corn plant just coming through the ground may be cut off by a cutworm. Its roots and leaves may be eaten by plant

lice. As it attains greater size, grasshoppers may feed upon the leaves, even destroying the entire plant. It may fall prey to the



U. S. Department of Agriculture

FIG. 317. The corn-borer was too widely distributed when it was discovered to be exterminated. The problem now is how to live with it. Entomologists have learned much of its life history. More knowledge will enable us to attack it at its weakest point. What control measures can you suggest?

European corn-borer (Fig. 317) or to one of the various corn-ear worms, with the result that it is rendered wholly unfit for our use.

Corn, wheat, and other grain crops are also subject to attack by such insects as the chinch bug, the Hessian fly, the army worms, and many others.

***Methods of control of insects that attack crops.** In order to control insect pests man must learn much about their habits: (1) He must discover facts concerning the life histories in order that he may know at what stage the insects can most easily be reached and killed. He must learn about each insect as a special problem, since their life histories vary so widely. For example, many of our insects pass the winter in the egg stage. With other insects the eggs hatch in a few days. (2) Man must understand the

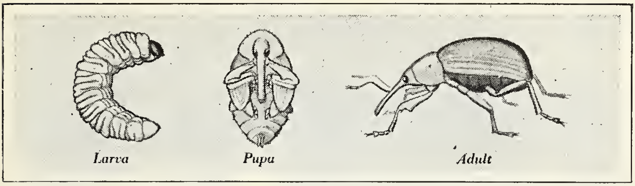


FIG. 318. The larva, pupa, and adult stages of the cotton-boll weevil. Special Report: Discuss the cotton-boll weevil (see "Suggestions for Effective Study," p. xi). Secure bulletins from the United States Department of Agriculture or from your state department

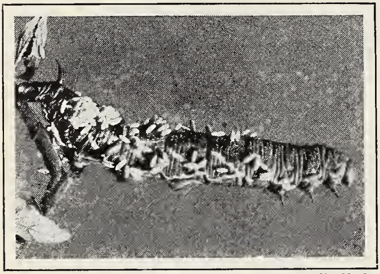
feeding habits; for when he knows what the insects eat and how they eat, he has gained an important key to the problem of control. (3) Man must learn what other organisms are insect enemies, in order to increase the numbers of these enemies. After he has gained this knowledge of the pests, man can usually employ effectively one or more of the following methods of reducing the insect population:

1. *Using poisons.* The chief means of combating many insects is the use of poisons. An insect which, like the potato beetle, eats the leaves of a plant may be killed by spraying the plant with a poison such as Paris green or arsenate of lead. But an insect like the squash bug, which gets its food by sucking the juices from the plant, would not be injured by poison on the leaves. Such an insect must be killed by contact poisons, that is, by poisons which either attack and penetrate the surface of the body or clog[1] the breathing pores. Among the commonest of such poisons are those containing nicotine, whale oil or fish oil, soap, kerosene, and sulfur mixtures.

2. *Rotating crops.* Rotation of crops is an important means of controlling pests that feed on only one kind of crop. The larvæ of the Western corn rootworm, for example, will eat only the roots of the corn plant. If fields infested with that pest are planted with wheat, oats, or clover, the rootworm may be starved. A similar method of control is applied in fighting the cotton-boll weevil. Since this insect feeds on the cotton plant only, the numbers of the pest can be reduced if no cotton is grown in the infested areas for two or three years. The practice in some localities of

[1] *Clog*: to choke up or obstruct.

growing crops other than cotton on land infested with the weevil has already proved of value in controlling the pest (Fig. 318).



Cornelia Clarke

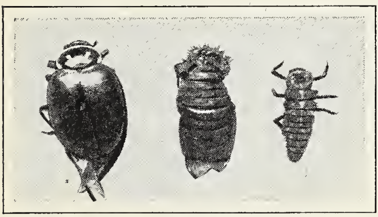
FIG. 319. A tomato worm infested with the cocoons of an insect parasite. What should you infer the life history of this parasite to be?

3. *Burning or plowing under.* Burning or plowing under the plant parts which remain after the harvest aids in control of some insects. The chinch bug may spend the winter in the stubs of the old plants, and the corn-borer in the cornstalks. Burning over infested fields will reduce the numbers of the insects that appear the following year. Both these insects, however, as well as many other pests may live through the winter in weeds or grass near the fields or in brush piles. The farmer must clean up all such possible hiding places as well as the field itself.

4. *Using knowledge of life histories.* A knowledge of the approximate time when the insect may be expected to appear to feed on the plant is essential to proper control. Thus food crops may be planted early or late in order to avoid certain pests which would attack the crops if the pests were in the stage in their metamorphoses in which they would feed on the plants. For example, spring wheat, planted late, is usually free from attack by the Hessian fly. Also late-planted corn is less liable to attack by the corn-borer. Another example of crop-timing is furnished by the apple industry. The time when spraying of apple trees is most effective in destroying the codling moth is just after the petals have fallen, for it is at that time that the moths lay their eggs; therefore the hatching larvæ may be killed by the poison before they get into the young apples.

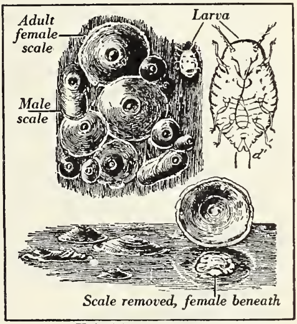
5. *Encouraging enemies.* The natural enemies of many insect pests help to keep them under control (Fig. 319). Birds, frogs, toads, skunks, and snakes are among the animals which feed upon certain injurious insects. Besides these enemies, many insects

are preyed upon by other insects. Ladybugs, or ladybird beetles (Fig. 320), eat plant lice, scale insects, and the larvæ of such insects as the potato beetle. The ichneumon flies (Fig. 249, p. 380) lay eggs in the bodies of many kinds of larvæ, chiefly caterpillars, or in the egg masses themselves, and the young parasites eat their hosts. Many of our worst pests are insects that were imported to this country while their natural enemies were left behind (Fig. 321). Entomologists are engaged in trying to discover and import these enemies, so that they may help to hold our pests in check. In some cases these efforts have proved successful. The cottony-cushion scale, for example, threatened to destroy the orange trees of California. A diligent search for natural enemies of the scale resulted in the discovery in Australia of a species of ladybug feeding upon this scale. So successful was the introduction of this insect into California that that particular kind of scale is no longer dangerous. Studies are now in progress to learn the natural enemies of some of our most rapidly spreading pests: the Japanese beetle, the Mexican bean beetle, and the corn-borer. It has recently been discovered that one of the roundworms is effective as a parasite of the Japanese beetle. Besides the insects and other animals which prey upon harmful insects, many kinds of fungi



Cornelia Clarke

Fig. 320. The adult, pupa, and larva stages of a ladybird beetle. The larvæ of various ladybird beetles feed on plant lice, the cottony-cushion scale, and other scale insects. What sort of mouth parts should you expect an insect of this kind to have?



United States Bureau of Entomology

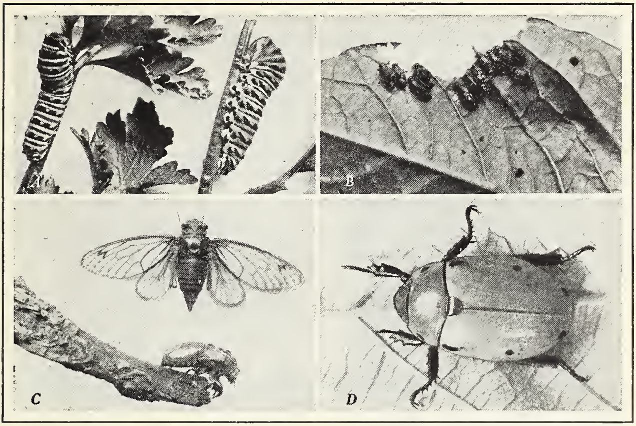
Fig. 321. San José scale. Special Report: Discuss the San José scale

have been found which parasitize them. It is possible, moreover, to plant the fungus in the body of a captured insect and then turn it loose to spread the disease to others of its kind.

Success in warfare against crop pests. Most of the insects considered are not and probably may never be entirely under control. All man's efforts serve only to reduce the numbers of the pests. One major victory, however, is even more complete than that over the cottony-cushion scale. This is the conquest of the Mediterranean fruit fly, which first appeared in this country in Florida in April, 1929.

The fruit-fly larva was discovered first in grapefruit, but it was soon learned that most fruits and many vegetables, such as tomatoes, eggplant, peppers, and beans, were also infested. All of that part of Florida in which the fruit fly was found was quarantined. No shipment of the host fruits or vegetables was permitted from the region. All infested places were thoroughly cleaned. All fruits and vegetables that might contain larvæ were destroyed. In order to rob the insects of places in which to lay their eggs, a law was passed prohibiting added planting of the crops which the flies might infest. Then, since it was known that the adult fly may live as long as ten months, measures were taken to kill off adult flies. Poison spray was placed on trees along roadsides and orchards. Traps were set in places where it seemed likely that the flies might collect. When the pest seemed somewhat under control, the quarantine was lifted to permit the shipping of fruit which had been sterilized either by heat or by cold to kill any larvæ that might be present. By November, 1930, so few of the pests were found in fruit examined and control measures were so well organized that it was felt that there was little danger of the fruit fly's spreading to other regions. The quarantine was therefore removed.

This brief summary of the methods used in controlling one pest that might have spread throughout the South and West shows what can be done when there is prompt and effective action by state and Federal authorities and the fruit-growers. The gypsy moth and cabbage butterfly are examples of what may happen when insect pests are accidentally introduced and are not controlled.



Cornelia Clarke

FIG. 322. The black swallowtail butterfly larvæ (*A*) and the cucumber beetle larvæ (*B*) injure plants by eating their leaves. The cicada (*C*) damages trees by shredding the twigs in order to lay its eggs within. (This cicada has just molted; the old case is left on the twig.) This beetle (*Pelidnota punctata*) (*D*), in both its larval and adult stages, feeds on the leaves of the grape. Special Report: Consult an insect book for the life history of each of these insects

***Summary of methods of controlling insect crop pests.** Man attempts to destroy those insects which are successfully competing with him for available food energy (Fig. 322) by (1) spraying the trees and plants with poisonous substances which will kill the insects that eat the leaves; (2) dusting the plants which he wishes to protect, with substances which will either injure the bodies of the insects or clog their breathing pores; (3) starving the insect pests through planting in the infested land a crop plant which the troublesome insects do not eat; (4) destroying the insects by burning over the infested land or by plowing the infested surface; (5) planting early or late in order to avoid certain insect pests; (6) directing the attack against the pest at the stage of its metamorphosis when the attack will prove most effective; (7) protecting and conserving the birds and other animals which feed upon insect pests; (8) importing and raising insect enemies;

(9) inoculating certain pests with parasitic fungi and then releasing the infected insects to spread the disease among their kind; and (10) quarantining infested regions.

Self-test on Problem XXV–B. **1.** The problem of insect pests is of *small* importance to *city* dwellers.

2. State five or more methods which are used in controlling insect pests.

3. Select from the following the insect which does not belong with the rest: (1) ladybird beetle; (2) Japanese beetle; (3) corn-borer; (4) pink bollworm; (5) cotton-boll weevil; (6) gypsy moth; (7) brown-tailed moth; (8) San José scale; (9) locust; (10) cottony-cushion scale.

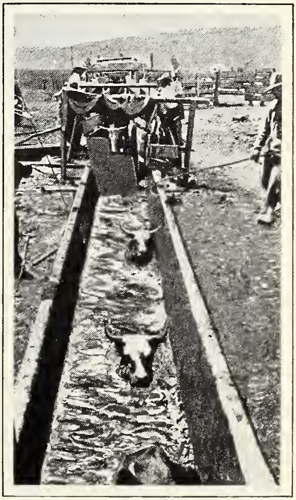
4. Thus far man has won *many* complete *victories* over insect pests.

Problem XXV–C · How can Man Control Pests that Attack Domestic Animals?

Pests that affect domestic animals. Lice, mites, fleas, and many kinds of flies annoy domestic animals by biting them and sucking their blood. These insects may also carry germs of diseases. One kind of tick is known to carry Texas cattle fever. Another carries the germ of Rocky Mountain spotted fever. Among the troublesome flies which injure horses and cattle is the botfly. This fly lays its eggs on hairs, usually on the legs. The horse or cow takes these eggs into its mouth while licking itself to remove the irritation caused by the presence of the eggs in the hairs. The larvæ develop in the stomach, often in enormous numbers. Since these larvæ feed as parasites, they do serious injury to the stomach walls of the host. Another fly which may often be a troublesome pest is the ox warble. It develops as a larva under the skin of a cow. When it is ready to pupate, it bores through the skin and drops to the ground. While it probably annoys the cow while living under the skin, the chief economic damage done by this pest is in injury to the hides.

Insect pests do damage of various sorts. (1) They sometimes kill domestic animals. For example, lice sometimes kill not only chicks but also mature fowls. (2) The pests may so torment the young animals that they do not develop normally. Young chickens infested with lice are robbed of too much energy to permit

their proper development. (3) The pests may cause an animal to lose flesh. (4) They may so weaken the animal as to make it an easier prey to disease germs. (5) They may so annoy or weaken the animal that it cannot produce the normal amount of the product desired. A cow annoyed by biting flies will produce less than her normal quantity of milk. A louse-infested hen will produce less than her normal number of eggs.



United States Bureau of Animal Industry

FIG. 323. Dipping cattle for ticks. Such parasites as the mange mite and the screw worm also attack the skin. **Special Report:** Consult an advanced textbook of entomology or zoology for facts about these parasites

One common method of fighting these pests is to kill the parasites upon the animals' bodies. Thus cattle and sheep are dipped (Fig. 323) to kill the ticks. Sodium fluoride is dusted among the feathers of a chicken to kill lice, or a small quantity of mercury ointment is rubbed into the chicken's skin. Another common method is to keep poultry houses, stables, and other living quarters as clean and sanitary as possible. Whitewashing fills cracks in which insect parasites hide. Disinfecting chicken roosts with a spray of kerosene or crude oil is effective in killing lice and mites. Removing the excrement daily from barns and poultry houses eliminates breeding places for various insect parasites.

Germ diseases. Animals are subject to a number of germ diseases. They are treated in much the same way as are people attacked by germ diseases. For certain diseases, such as hog cholera and anthrax, serums are administered in much the same way as for human beings, to give immunity or to aid the animal in recovering from the disease. Animals with certain diseases are quarantined to prevent the spread of the diseases. Also, newly purchased animals are kept separated from other animals for a

length of time sufficient to show whether or not they have contagious diseases. It is unlawful to transport an animal from some states into others unless the animal is accompanied by a veterinary's[1] certificate that it is free from infectious diseases.

Self-tests on Problem XXV–C. **1.** Select from the following the animal which does not belong with the rest: (1) botfly; (2) Japanese beetle; (3) flea; (4) louse; (5) ox warble; (6) tick; (7) mite.

2. State four or more kinds of damage done by insect pests which attack domestic animals.

3. *No animal* diseases can be successfully treated by the injection of serums.

4. *Sick animals* are often quarantined.

Problem XXV–D · How can Man Control Certain Fungous Diseases of Plants?

Agricultural production and the fungi. Insects are not the only organisms which take toll of our cultivated plants. There are many kinds of parasitic fungi which cause damage amounting to many millions of dollars annually. Among these are the bacteria, rusts, smuts, mildews, and blights. Few of our crop plants are free from the attacks of some of these.

Wheat rust. Perhaps the most serious of plant diseases are the rusts, which affect wheat, oats, barley, and rye. The common wheat rust appears on the stem, leaves, and even the grain itself, forming reddish patches (Fig. 324). The threadlike body of the parasite extends into the plant tissues, absorbing the food material and destroying the protoplasm. As a result of the destruction of the food-making tissue the grains are light and shriveled. The wheat plant becomes weakened also and will blow over easily. The life history of this parasite is like that of some others we have studied in that it usually requires two hosts, the wheat plant for one stage and the common barberry for the other. The red patches of spores described above are produced throughout the summer and may infect one wheat plant after another. Later in the summer the fungus produces black spores which live through the win-

[1] *Veterinary* (vet′er i na ry): a man trained in medical and surgical care of animals.

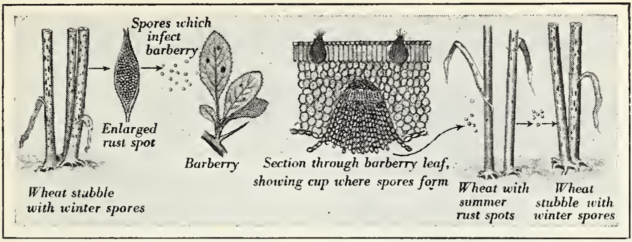


FIG. 324. Life cycle of wheat rust. Can you explain this diagram? (See text)

ter on the stubble or on grasses or weeds in or near the field. In the spring these black spores produce a third type of spore, which is carried to the barberry by the air. Here it grows and produces a cuplike pit on the underside of the leaf. Within this depression are formed many spores which may again infect the wheat.

As in the case of any parasitic organism which requires two hosts for its life cycle, the destruction of either host results in the destruction of the parasite. If, then, the common barberry is removed from the vicinity of wheat fields, there is little probability that rust will attack the wheat. In 1903 Denmark destroyed all the common barberry bushes in the country and has not since been troubled with rust epidemics. It has been discovered, however, that in warmer regions, where the host plants are not killed during the winter, the red-spore stage of the rust may live on certain grasses and weeds and infect the young wheat when it appears. Moreover, where winter wheat as well as spring wheat is planted, the rust may be present on the wheat the year round. The only methods of reducing the danger from rust epidemics in such regions are (1) removing from the field all weeds and grasses which might harbor rust, and (2) planting varieties of wheat that have been found to resist the disease.

Other rusts. There are other rusts which do great damage to cultivated plants and which have similar life cycles on two hosts. A rust which attacks the fruit of the apple tree spends part of its life on the cedar. Here in the fall it produces "cedar apples," which are round dark-brown growths on the cedar branches. In the late spring, following a warm rain, the cedar apples become

yellow and jellylike, due to the millions of spores they produce. These spores are blown everywhere and infect the new apple leaves. No way of controlling this disease has yet been discovered except to remove all cedar trees from the vicinity of apple orchards.

Fig. 325. Corn smut. Special Report: Compare its life cycle with that of the wheat rust. (Consult an encyclopedia)

White-pine blister rust, a fungous disease recently introduced to this country, is proving extremely destructive. The alternate host in the life of this parasite is a gooseberry bush or a currant bush.

Some other fungous diseases. Smuts attack corn, oats, wheat, and barley, and produce masses of spores which destroy the infested grain. The spores are carried over from one year to another on any remaining good grain or in the ground (Fig. 325).

Mildews attack the leaves of many plants, as the lilac, cherry, and peach. They may cover the entire surface of the leaf, making it look as if it had been powdered. Poison sprays are sometimes effective in controlling mildews.

Potato wart is a serious disease which was introduced into the United States in 1911. Since then it has spread over most of the eastern part of the country. The fungus produces on the surface of the potato tuber spongy growths in which the spores are developed. Control measures consist of destroying diseased potatoes and of planting other crops in the infected soil. It is said that the spores of potato wart can live in the soil for as long as eight years.

Self-test on Problem XXV–D. 1. Select from the following names the one which does not belong with the rest: (1) mildew; (2) bacteria; (3) smuts; (4) blights; (5) plant lice; (6) barberry; (7) potato wart.

2. In order to complete its life cycle the wheat rust requires *alternate* hosts.

3. Select from the following the name which does not belong with the rest: (1) gooseberry; (2) barberry; (3) red cedar; (4) currant; (5) white-pine blister rust; (6) wheat; (7) oats; (8) rye; (9) barley.

4. The fungous parasites of crop plants are reproduced by *seeds*.

5. The fungous diseases of crop plants are *saprophytes.*

6. The most serious of the fungous diseases are __(?)__

Self-test on Biological Principles. 1. What evidence can you cite to illustrate this biological principle: "All the higher forms of terrestrial[1] life are dependent either directly or indirectly on soil bacteria for their nitrogen intake"?

2. Can you explain in terms of the definition of biology what is meant by "whether man or the insects will finally conquer in their constant warfare"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. How many examples of parasites requiring alternate hosts have been discussed in this book up to this point? After you have made your list, check it against the references under "Alternate hosts" in the Index.

2. Why is it that soil is rarely found consisting of only one kind of particles?

3. Can you name examples, not given in this text, of the dependence of plants upon particular kinds of soil?

4. Why is it that soil bacteria are most numerous in soils that contain the most humus?

5. Why are soil bacteria more numerous near the surface than deeper in the soil?

6. Of the animals named in this chapter as enemies of insect pests, which are parasites? which eat the pests as prey?

7. Why is it a good practice to permit leaves and other plant parts to remain on the ground until they decay? When might such a practice be undesirable?

8. Are plants which grow along roadsides useful or harmful? Why?

9. Are the bacteria of decay parasites or saprophytes? Explain.

10. Do the nitrogen-fixing bacteria which grow on clover roots furnish an example of parasitism, saprophytism, or symbiosis? Explain.

Project 21. To kill any insects found on plants in the home or greenhouse. Watch the insects to determine how they feed. Which of the methods given in this chapter will you use to kill them? Consult reference books or visit a florist to learn what poisons will kill the insects without injuring the plant. Report to the class on your methods and their success in getting rid of the pests.

[1] Terrestrial (ter res′tre al): pertaining to the earth.

Special Reports. **1.** What household pests are most common? How are they injurious? How can they be exterminated? Consult bulletins from the United States Bureau of Entomology.

2. Which of the common garden or flowering plants thrive best in each of the following soils: sandy soil, sandy loam, clayey loam, clayey soil?

3. Make a list of the important pests of your state; of your vicinity. From the United States Department of Agriculture secure bulletins explaining how these pests may be combated. Report the success of these measures.

4. Read in Paul De Kruif's *Microbe Hunters* the story of the discovery that the tick carries Texas fever.

5. Read in Paul De Kruif's *Hunger Fighters* the story of the development of rust-resistant wheat. Write to the Bureau of Plant Industry, United States Department of Agriculture, for up-to-date information concerning the amount of damage done by wheat rust; white-pine blister rust; potato scab; potato wart; cabbage yellows.

Chapter XXVI · The Conservation of Natural Resources and Wild Life

Questions this Chapter Answers

What is meant by conservation of wild life?
Why should forests be conserved?
What are the enemies of the forests and how are they being combated?
Why should birds be protected?
What is being done toward bird protection?
Why should man protect any wild animals?
What mammals are man's worst enemies?
What is being done toward fish conservation?
Are there any other water animals besides fish which ought to be conserved?

Problem XXVI–A · What are Important Problems of Forest Conservation?

The need for conservation. Conservation of natural resources, particularly those based upon forests, depends on both personal and public effort. Recently the results of too rapid use of such resources have made apparent the need for a clear understanding of the entire problem of forest conservation.

Forest conservation, properly defined, means the using of the trees in such a manner that the value of the land as a producing property is maintained. It does not mean the preservation of native woods without use.

When the early settlers came to America fully half the land was covered with forests. Today, through cutting by men and damage by fire, fungi, and insects, scarcely half the original forest area is producing trees. Timber consumption today is said to be four times as great as timber production. At the present rate of use, therefore, the forests will certainly disappear unless there is sufficient provision for replacement.

Value of forests. Wood still remains the best material for many uses. It is extensively used in house construction, interior finish,

U. S. Forest Service

FIG. 326. Cherokee National Forest, Tennessee. When the forests disappear, rapid erosion follows. Compare this figure with Fig. 348, p. 545

and fine furniture. Among the valuable by-products made from wood are wood alcohol, charcoal, and certain kinds of gums and dyes. Wood pulp is the cheapest and most satisfactory material for newsprint. The forests of the southern United States furnish vast quantities of tar, resin, and turpentine. Yet even now some of these articles are imported because we do not produce enough for our needs. The bark of hemlock and certain oaks is used in tanning processes. The New England states produce maple sugar in large quantities. As a result of research,[1] and especially chemical research, it is reasonable to expect a great expansion in the use of wood. Rayon is a good illustration of one of the new uses.

*Forests are of value not alone because of the wood they furnish. Perhaps of equal importance is their work in regulating the rate at which water runs off into the rivers and in preventing the erosion and removal of soil (Fig. 326). The soil in a forest is largely humus, composed of decaying leaves and other vegetation. This material acts like a sponge in absorbing rainfall and the water from melting snow, thus preventing water from running off too rapidly. Serious flood damage is likely to be the result of cutting or removing forests from stream headwaters. From such barren hillsides soil and rocks are washed down and are carried along by the water. Such ero-

[1] *Research* (re search′): the scientific investigation or study of a problem.

FIG. 327. What protective measures other than fire prevention are necessary to preserve such animals as these? What can you do in your own community to protect them? What biological principle is illustrated in the second picture?

sion results in adding to the volume of the flood, filling up stream beds, cutting new and deeper channels, and covering fertile valleys with stones and other material.

In southern California, in particular, it has been found that after forest fires the natural openings of the soil surface are almost closed by ashes. It is difficult, therefore, for the water to soak in. As a result most of the rain which falls runs off rapidly. Forests do not prevent floods entirely, but they greatly reduce their damaging effects.

*Forests have another important relation to rainfall. The roots take up great quantities of water during the seasons when the leaves are manufacturing food. Much of this water is passed off through the leaves in transpiration, as has been explained in Chapter V.

Forests have long been recognized as the natural home of wild life (Fig. 327), and in earliest times forests were reserved and protected because of the hunting they afforded rather than for their wood products. In many parts of the United States, regions from which game had disappeared have now become replenished with

wild life, especially deer and smaller animals, through reforestation, protection from fire, and better public observation of conservation principles.

Self-test on Problem XXVI–A. **1.** When forest conservation is carried on in the proper way, trees are *never* cut.

2. *Man* has been one of the chief factors in reducing forest areas.

3. At present, forests are *increasing* more rapidly than they are *diminishing.*

4. Forests prevent *erosion.*

5. Wild life has *increased* as the forests have *diminished.*

Problem XXVI–B · What are the Most Serious Enemies of Forests?

Forest enemies. *Man.* Man is directly responsible for much of the decrease in forest resources. In pioneer days forests seemed abundant beyond human needs. Trees were so numerous that there was little need for care in cutting them or in using wood. Land had to be cleared to provide farms and to build cities. But too much of the cutting was done without thought for the future. Often lumbering methods were such that the smaller trees were destroyed, or the fires which followed lumbering burned over the land so completely that it is still nonproductive. The damage done was usually not the result of a single fire but of repeated fires which gradually killed all tree growth, so that no seed trees were left. In time other vegetation disappeared until finally all the humus, or plant food, was destroyed. Many tracts of land were cleared for farms only to have it discovered later that because of the poor soil or other reasons the land was not suitable for agriculture. There are in the United States today about eighty million acres of idle land best suited to grow forest crops. One of the most important present-day problems is to put that land again into forest uses (Fig. 328).

Forest fires. Fire destroys more trees than are cut for use (Fig. 329). In 1927 thirty-eight million acres were burned over. It is estimated that it would cost three hundred million dollars to

U. S. Forest Service

FIG. 328. Reforestation in Huron National Forest, Michigan. Can you suggest reasons why it might be more profitable to plant trees than corn or wheat on such land?

U. S. Forest Service K. D. Swan

FIG. 329. Such a fire as this may have started from a glowing match or cigarette. What damage to the forest is shown in these pictures?

reforest[1] this region. Most of the forest fires are caused by man's carelessness. Lightning and other occurrences which cannot be prevented probably do not account for more than 10 per cent of

[1] *Reforest* (re for'est): to cause forests to grow again on barren areas. *Reforestation* (re for es ta'shun): having to do with reforesting.

the forest fires in the eastern part of the United States. The other 90 per cent could be prevented. Some fires are built by people who want to clear the land for grazing or for other purposes. The fires may get beyond control and sweep vast areas. A considerable number of fires are caused by campers who build fires in dry grass or leaves, or who leave a bed of smoldering coals. The careless smoker is now by far the greatest cause of forest fires. If every smoker would take care that no glowing match or burning tobacco is thrown down, the danger from fire would be greatly reduced.

Insects. There are two hundred thousand kinds of insects which are known to attack forest trees. They do damage estimated at one hundred million dollars a year. Some feed on the leaves and thus lessen the ability of the tree to make sufficient food. Insect larvæ may bore into the bark or wood, cutting off the flow of sap, ruining the tree for lumber, or perhaps weakening it to such an extent that it may be blown over by strong winds. Scale insects also do some damage.

Probably the most effective means of control of insects is through their natural enemies, the birds and certain parasitic insects that feed upon those injurious to trees. In some cases natural controls are aided by man. Sometimes eggs and larvæ and even the adult insects are collected and destroyed. Spraying, which is done in orchards, is usually not practical over extensive forest areas.

Fungi. Fungous diseases of various sorts, such as the chestnut blight and the white-pine blister rust, previously mentioned, threaten the forests in some parts of the country. Almost the only method of control of fungous diseases lies in cutting down and destroying infected trees. Quarantine laws which keep out undesirable insects and fungi from other countries are also effective as controls.

Waste. Waste in the use of forest resources is as bad as any other waste. Sometimes, however, a so-called waste is in reality only a loss. It may cost more in time or energy to use a thing than to leave it unused. Leaving branches and twigs in the woods to decay is not a waste if there is no market for them. Cutting off the slabs in making lumber is not waste, since boards of regular dimensions are necessary.

Timberland owners who harvest their timber in such a way that lands best fitted for continuous forest crops are left completely bare are guilty of waste. High stumps and good logs left in the woods, and trees which are damaged by careless cutting, also constitute a waste.

In this connection it should be pointed out that Christmas trees are valuable forest products, and their use should be encouraged. Such trees produce good crops and make possible an early return from the forest. Moreover, their cutting, if properly done, gives the remaining trees needed room for proper development.

Self-test on Problem XXVI–B. 1. The most serious enemy of the forests has been (1) fire; (2) lightning; (3) insects; (4) man; (5) fungi.

2. *All* land where forests have stood is unsuitable for agriculture.

3. Lightning is the cause of a *relatively large* proportion of forest fires.

4. Tobacco has been indirectly the cause of *much* forest destruction.

5. Certain *saprophytes* are effective in killing some organisms which attack forest trees.

6. The use of Christmas trees should be *forbidden.*

Problem XXVI–C · By What Means are Forests Conserved?

Forest conservation. European countries have passed through the stage of having vast natural resources and later experiencing their absence. Many European countries, therefore, can point the way to the proper use and care of forests. They discovered years ago that productive forests are profitable investments. In Germany, for example, a woodland is treated much like any other crop-producing area. Mature trees are cut and used, the smaller trees are protected from injury, and young seedlings are planted to replace the trees that are removed. Thus there is a continuous supply of wood ready for all needs.

*The United States once had abundant resources and few inhabitants. People were encouraged to use these resources. Then gradually these natural resources passed into the control of a few people, who often exploited them in ways that were harmful to the interests of the United States as a whole. No one appreciated the speed with which the forests were disappearing. Only re-

cently, moreover, have people recognized that there can be too much land used for agriculture. Since they believed that there was an ample supply of timber and that the timbered land was best suited for farming, there was no apparent need for keeping the land in forests. Trees were cut without regard to the younger trees, and no effort was made to leave seed trees. Sheep and cattle cropped the vegetation of certain areas too closely. The relationship between forest cover and water supply and flood control was not considered. The principle of providing the greatest possible amount of good for the greatest number of people was not recognized.

Fig. 330. Saginaw Forest, belonging to the University of Michigan. How does planting the trees so thickly help to produce better lumber?

In recent times progressive owners of forest land have been concerned with practicing methods of cutting, protection, planting, and fire control which will insure a permanent supply of timber (Fig. 330). Where there is still much native timber, as in the western part of the United States, in Canada, in parts of the South, and to some extent elsewhere, private owners are beginning to practice forestry. In parts of the United States where all the timber has been cut, where repeated fires have reduced the value of the land, or where natural conditions of soil and growth are not favorable, it is probable that either the national or the state government will take control.

Most of the states now have forestry organizations, and many of them own extensive forest properties. It is expected that each state will in time develop a "land-use" program which will include the development of forests, wild life, and opportunities for recreation in addition to the establishment of better control of erosion.

National interest in the conservation of natural resources was stimulated during 1933 through the work of the Emergency Conservation Program. As a part of the program for the relief of unemployment more than two hundred fifty thousand men were put to work on reforestation in many parts of the country.

Care of trees near our homes. We plant and care for trees in our yards or along our streets and roads, both for their beauty and for the shade they provide. Among the most desirable trees for such planting are various species of maple, ash, elm, and oak. These trees are good shade trees because they branch widely and have large and numerous leaves. Furthermore they do not continuously shed leaves, bark, and other litter on lawns and sidewalks, as do some other trees.

Trees which have been injured by wind, lightning, or decay should be cared for before their ruin is complete. Broken branches and diseased parts are first cut away. Then the cuts are covered with paint or tar to keep out insects and fungi until the part is completely healed. Large cavities may be filled with cement. Heavy branches may be wired or bolted together to keep them from splitting and ruining the tree.

Self-test on Problem XXVI–C. **1.** Forest conservation is carried on *more* effectively in North America than in Europe.

2. Forest conservation is being carried on *more* effectively in the United States and Canada than formerly.

3. In the United States forest conservation is under the control of the Department of *Justice.*

4. *No* forests now pay for the cost of maintaining them.

5. Injured shade trees can often be successfully treated by the use of *medicine.*

Problem XXVI–D · Of What Importance to Man are Birds, and How can they be Protected?

***The value of birds.** Birds are among man's most important aids in reducing the numbers of plant and animal pests. They eat weed seeds, harmful insects, and destructive rodents, and some act as scavengers as well (Fig. 331). Since most of their activities

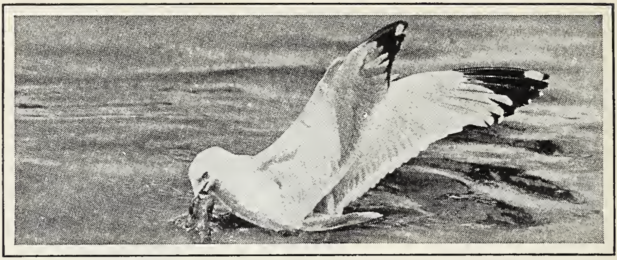


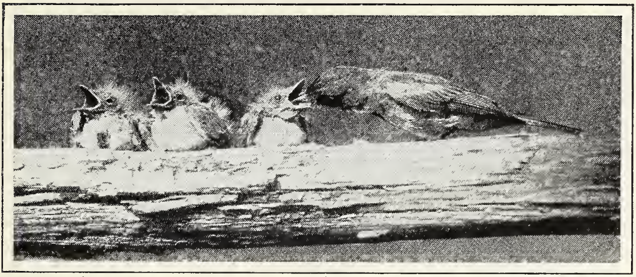
Fig. 331. Of what importance to man is the fact that the gull is frequently a scavenger?[1]

are concerned with the business of getting food, they are able to destroy enormous numbers of such plant and animal pests every year.

Birds as insect-eaters. It has been said that if it were not for the birds, within ten years the insects would become so numerous that man would find it almost impossible to live. Whether or not that statement is true, it is true that birds destroy countless numbers of injurious insects (Fig. 332). Among the birds that feed almost entirely on insects are the wrens, warblers, swallows, woodpeckers, fly-catchers, and cuckoos. The bluebird eats cutworms, tent caterpillars, beetles, grasshoppers, and codling moths. The yellow-billed cuckoo feeds upon hairy caterpillars such as the tent caterpillar, though most birds avoid these larvæ. In the stomach of one cuckoo two hundred fifty tent caterpillars were found. The Baltimore oriole eats hairy caterpillars, and in addition it feeds upon the cotton-boll weevil, beetle larvæ, and plant lice. The downy woodpecker finds most of its food upon and under the bark of trees. It eats codling-moth pupæ and those boring insects that are so hard for man to combat. The meadow lark feeds mostly upon beetles, caterpillars, and grasshoppers. The flicker, though belonging to the woodpecker family, feeds largely on ants.

Birds as weed-seed eaters. Much of the energy the farmer spends in trying to raise his crops is used in combating weeds. They often grow faster than the desirable plants, shading the tiny seedlings from the necessary sunlight and using up the available

[1] Photograph by Frank N. Wilson. Used by permission of *Nature Magazine.*



L. W. Brownell

FIG. 332. Phœbe feeding insects to its young. How many other birds can you name that are insect-eaters?

water in the soil, thus killing the crop or hindering its growth. It is estimated that the farmer loses a dollar an acre every year because of the damage done by weeds. He spends much of his time plowing up weeds or digging them out of pastures and fields. He must cut those growing along fences or roadsides before their seeds ripen, in order that the numbers of weeds in cultivated fields may be reduced the following year.

Perhaps we do not always recognize the great value of seed-eating birds as destroyers of weeds. Especially important are those birds that remain the year round, feeding largely on seeds in the winter. The seeds most commonly eaten are those of such weed pests as ragweed, pigeon grass, pigweed, crab grass, smartweed, and purslane. Almost three hundred species of birds are known to feed on weed seeds. Many of these belong to the sparrow family and include the native sparrows, such as the tree sparrow, song sparrow, field sparrow, and chipping sparrow, as well as the junco, the buntings, finches, and grosbeaks. Birds of other families also prominent as seed-eaters are the quail (Fig. 333), mourning dove, red-winged blackbird, and meadow lark.

An examination of the stomachs of various birds shows interesting facts. Several hundred seeds of pigeon grass were found in the stomach of a tree sparrow. One thousand pigweed seeds were found in the stomach of a snow bunting. Five thousand seeds of pigeon grass were counted in the stomach of a quail. Seven thousand five hundred seeds of yellow sorrel were found in the stomach

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Fig. 333. Birds which, like the quail, remain through the winter are among the best weed-seed destroyers. Why is this true?

of a mourning dove. One investigator estimated that the tree sparrows alone eat eight hundred seventy-five tons of weed seed per year in the state of Iowa.

Birds as rodent-destroyers. Hawks and owls (Fig. 334) are the natural enemies of the rodents which feed upon crops. Hence these birds are man's most effective aids in reducing the numbers of these pests. We do not always appreciate the economic value of such birds, because of their reputation as chicken-killers. Some kinds of hawks may kill chickens, but by far the greater number that we see circling about the fields and pastures are searching for mice, gophers, squirrels, or rabbits.

Which birds are useful and which harmful? It is usually a mistake to label any bird as useful or harmful, because few will come wholly within either classification. The usefulness of a bird may or may not exceed its harmfulness. A bird may be of value at one time of year or in one locality and of no value in other places or at other times. For example, the bobolink is useful as an insect-destroyer in the North, but it is a harmful nuisance in the rice fields of the South. The robin is sometimes condemned for eating our cultivated fruits, but over half its food consists of insects that would destroy more fruit than the robin can eat. The turkey buzzard has been considered of such value as a scavenger that in some states there is a fine for killing it. Of late, however, there is some evidence that the bird may do great damage by

carrying hog cholera and perhaps other diseases from dead animals on which it feeds to places where new victims may be infected.

The English sparrow was introduced into this country in 1851 to help to combat the insects that were destroying shade trees in cities. But it did not then prove of value as an insect-eater. Moreover, it threatened to crowd out native insect-eating birds such as the wrens and the bluebirds. Many cities tried trapping, shooting, and poisoning the sparrows to get rid of them. Recently, however, in more densely populated cities where the native birds do not venture, the English sparrow is of benefit in keeping shade trees free from insects. Reports indicate that the bird is also proving of value as an enemy of the Japanese beetle and of the Colorado potato beetle.

United States Bureau of Biological Survey

FIG. 334. Barn owl and skeletons of small mammals near its nest. **Self-test on Biological Principles:** State in complete sentences the biological principles which these pictures suggest to you

The starling is another immigrant whose coming and rapid spread over the country have often seemed undesirable. But this bird has been found to feed on the Japanese beetle and the Colorado potato beetle, hence may finally "pay its way."

Need for conservation of birds. Native birds have undoubtedly become less abundant than they were a century ago. Many species have been unable to adapt themselves to changing environments. As woodlands were cut and marshes drained they retreated farther and farther from the neighborhood of man in search of breeding places and food. Some birds, like robins, martins, and swallows,

seem to adjust themselves to civilization and to thrive even better than in their native state. But these constitute the exception rather than the rule.

Perhaps the hunter is most clearly responsible for the disappearance of certain birds. He has hunted birds for their skins or feathers, for food, or just for fun. Some years ago the Chinese pheasant, one of the finest and most beautiful game birds, had practically disappeared from certain localities of the western United States where they were once abundant. A law was passed prohibiting hunting of these birds for five years. At the end of the five years the pheasants were abundant.

A number of native birds have become entirely exterminated within recent times. The causes of these exterminations are not fully known. There is no doubt that hunting was at least partly responsible for the disappearance of the passenger pigeon and the heath hen. Yet it is likely that diseases or insect parasites had a large share in all such exterminations. Some recent investigations into the cause of the diminishing numbers of a certain species of duck once plentiful in Middle Western lakes revealed the presence of a small insect parasite which is believed to be chiefly responsible for the bird's rapid disappearance.

Conservation laws. While it is impossible to protect wild birds from parasites, it is easy to prevent their destruction by hunters. Laws which protect them are one means of conservation. Because of such protection the wild turkey and some of the herons which seemed on the verge of extermination are now increasing in numbers. Among the birds still threatened with extermination are the upland plover, the wood duck, and the woodcock (Fig. 335). Although these birds are protected during certain seasons, their numbers are steadily decreasing. Further laws for their protection are needed.

In 1886 a model law for the protection of nongame birds was drafted by the American Ornithologists Union. This law defines game and nongame birds and prohibits the killing of the latter or the collecting of their eggs. Nearly all states now have laws which are based on this one. As years have gone by, other laws which give protection have been passed. The Lacey Law prohibits the shipment of birds out of a state in which it is illegal to kill them.

Another law, known as the McLean bill (1913), forbids the killing of insect-eating birds at any time. It also provides for short open seasons when game birds may be killed, protecting them at all other seasons. In 1916 the Migratory Bird Treaty between the United States and Canada was made. It is designed to give protection for all song birds at all times. This law is a very important one, for it protects these birds both during the nesting season and during the time they are on their way to and from nesting grounds. In 1929 a Bird Refuge Law was passed by Congress. This law provides money to purchase areas for bird sanctuaries and to provide for their maintenance.

George Shiras III

Fig. 335. Wild ducks rising from one of the ponds on the Rainey Wild Life Sanctuary, Louisiana. This refuge consists of twenty-six thousand acres, and is administered by the National Association of Audubon Societies. **Special Report:** What are the history and the purposes of the Audubon Society?

Increasing bird life. Many states have bird sanctuaries or wild-life preserves which aid in bird protection. National forests and national parks serve also for homes and nesting grounds. Then, too, many individuals have set aside tracts of land for bird sanctuaries.

Man has taken a direct part in the propagation of certain game birds which it seems desirable to increase. The eggs of pheasants, quail, and mallards, for example, can be hatched and the young raised like poultry. When of sufficient size the birds may be distributed to wild regions that need restocking.

If we wish to encourage the presence of birds near our homes, we must provide the sort of environment they like. Trees, shrubs, or bushes will provide fruits for food and places for nests. Bird

houses or boxes attract some kinds of birds. In winter, food placed in convenient feeding places will attract many birds.

Self-test on Problem XXVI–D. **1.** Birds are important in destroying insects, __(?)__, and rodents.

2. The quail is especially valuable because it eats such enormous quantities of *rodents.*

3. A bird useful in one locality *will* be *useful* in another.

4. The English sparrow is of *some* economic importance.

5. *All* birds that have disappeared during the last century have been exterminated by man.

6. *All* birds should be protected by law.

Problem XXVI–E · In What Ways are Wild Mammals Important to Man?

Protection of wild animals. One authority tells us that the number of wild animals in the United States today is only about 2 per cent of the number of those which once lived here. As any country is settled, the wilder animals are driven from their native haunts. Many are killed for food or for furs. Others, unable to adapt themselves to changed conditions, gradually decrease in numbers.

The bison, which once roamed in vast herds over most of the United States and Canada, are now found chiefly under protection of national parks (Chapter XXVII). They were practically exterminated by hunters who killed them for the hides or just for sport. A few thousand are found in Yellowstone National Park. There are small herds at Wainwright, Alberta, and in some of the Canadian national parks (Fig. 336). The protection afforded by the parks has kept them from being exterminated in the United States and Canada.

We have been more fortunate in our conservation of some other mammals. Laws which protect them at all times or during all but a brief hunting season were enacted in time to prevent too great destruction. Suitable forest and other lands were set aside, where they might live. As a result deer of various kinds, moose, and elk are found in many parts of the country.

FIG. 336. Bison herd, Riding Mountain National Park, Manitoba. How many reasons can you suggest which justify the conservation of these animals?

The beaver was almost exterminated by overtrapping. Now that it is protected by law its numbers are increasing in many localities. Seal-fishing on the islands near Alaska had to be prohibited for a number of years to permit the animals to multiply. The fishing now is closely regulated by law. In spite of laws protecting the sea otter of Alaska that valuable fur animal has been practically if not wholly exterminated.

Many other animals are protected by closed seasons. Laws prohibit the killing of certain kinds at all times, and of others at least during the seasons when they are rearing their young. Animals protected in this manner in many states include the raccoon, muskrat, and skunk. Other laws provide a bounty for killing certain undesirable types, such as the mountain lion, which prey on deer, elk, and other animals that it is desired to have increase.

The degree of protection which may be extended to an animal depends partly on its abundance and partly on its value or on the harm it does. Thus an animal may be protected in one state but not in another.

***Value of animals to man.** The reasons for protecting wild animals are not only those of sentiment. They are practical as well (Fig. 337). Animals like the skunk are valuable insect-eaters. Besides the food furnished by game animals, many mammals fur-

nish fur that is of considerable value. Some of the fur-bearers — for example, foxes, mink, skunk, raccoon, and muskrat — can be raised in captivity. Such animals are killed humanely and do not suffer in traps as do the wild fur-bearers. To be successful in fur-farming, one must learn all he can about the habits of the animal he wishes to keep. He must know the kinds of food it will eat, the type of home it prefers, its enemies, and the diseases to which it may be subject.

John Edwin Hogg

FIG. 337. While snakes eat harmful rodents and insects, they are not so valuable as pest destroyers as are birds. Why is this statement true?

Rodent enemies of man. Some wild animals are enemies of man. The rodents, or gnawing animals, are very numerous; in fact, the family (Muridæ) of rodents to which the mice and rats belong includes about one fourth of all the mammals. Among the rodents there are several families, the squirrels, gophers, rabbits, mice, and rats, which are extremely destructive of food and property. The squirrels and the gophers do their chief damage to farm and garden crops, though some of the squirrels also destroy birds by eating their eggs. Rabbits eat only vegetable food, including fruit. They are especially fond of garden and farm crops, such as peas, cabbages, clover, and alfalfa, and many flowering plants. They also feed on the branches and bark of young trees and shrubs and thus do considerable injury to ornamental trees and shrubs, to fruit trees, and to forest trees. Rabbits are of some value to man for food and for fur, which finds considerable use under such trade names as *lapin* and *cony*.

*The rat is said to be the most dangerous pest of all the mammals. It is responsible for the direct loss of hundreds of millions

of dollars annually in addition to the indirect loss caused by diseases which it and its parasites carry. The rat makes his home with man and accompanies him to all parts of the world. Rats eat most of the kinds of food used by man. They consume great quantities of grains, fruits, vegetables, and meats. Often, moreover, they injure or destroy more than they eat. One authority says that they kill more chickens, ducks, geese, and other domestic fowls than foxes, skunks, weasels, minks, owls, and hawks combined. They damage with their gnawing all sorts of merchandise other than foods, also furniture and even buildings themselves. Because of its intelligence the rat is a difficult animal to poison or to trap. Moreover, contrary to general belief, the house cat is not always an effective means of killing rats. The rat is ferocious. When in numbers, rats will attack any animal and have been known to attack babies and even to kill men. Ratproof buildings provide an effective means of keeping rats away.

Mice, though less destructive and dangerous than rats, nevertheless do great damage to garden and farm crops and to foods of all kinds. It is estimated that a single field mouse requires from twenty to thirty-six pounds of green plant food per year. When this food consists of farm crops, it is easy to understand that the loss to a farmer from mice may be many tons per year.

Self-test on Problem XXVI–E. 1. Laws passed to protect wild animals are *always* effective.

2. The most harmful of all enemies of man among the mammals is the __(?)__.

3. Animals such as the muskrat and beaver are killed chiefly for their *meat.*

4. The skunk, raccoon, mink, fox, and *coyote* are raised in captivity for their furs.

5. The mammals which are most destructive to farm crops are the *ungulates.*

6. A mammal which has been practically exterminated because of its valuable fur is the __(?)__.

7. Unlike *rabbits, rats* will eat only plants, though they eat many kinds of plants.

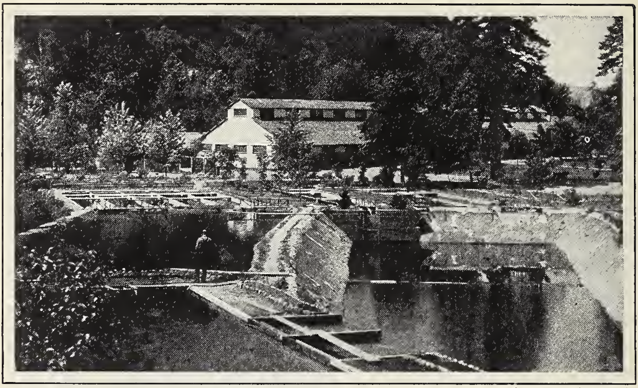

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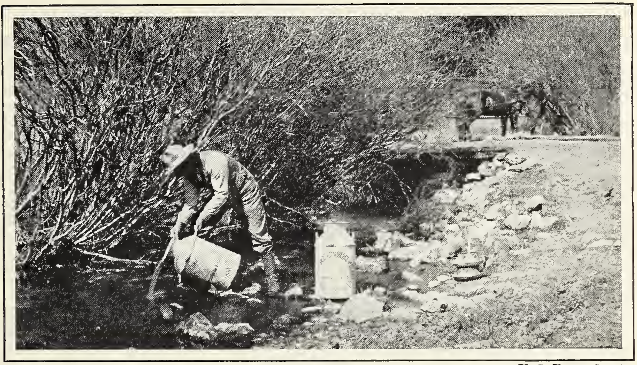
FIG. 338. Fish hatchery, Bonneville, Oregon. **Special Report:** Are there fish hatcheries in your state? If so, what kinds of fish are raised? Write to your State Department of Conservation for information

Problem XXVI–F · How can Man Make Rivers, Lakes, and Oceans More Productive?

***Fish conservation.** In order to prevent the overfishing of valuable species most states have laws which limit the size and number of fish which can be taken and which prescribe the methods that may be used. The laws prohibit the use of such methods as exploding dynamite in the streams, since such practices kill young fish as well as those which are large enough for use. For the same reason nets with too small mesh are prohibited. During the breeding season many species of fish may not be legally taken.

Much damage to fishing occurs through the pollution of the waters by sewage, factory wastes, and oil wastes from oil-burning steamers. These wastes not only injure or kill the fish directly, but by preventing the growth of the plants and small animals which serve as food prevent the growth of young fish.

The Bureau of Fisheries has been engaged for many years in collecting information concerning the kinds of food required, the enemies, the breeding habits and other life habits of many of our fish. Many fish hatcheries have been established, by both state



U. S. Forest Service

FIG. 339. Putting young fish into a fished-out stream, Black Hills National Forest, South Dakota. Self-test on Biological Principles: Will all these young fish grow to adult size? State a biological principle to justify your answer

and national governments (Fig. 338). The eggs are artificially fertilized, and the young are cared for until they are large enough for their chances of survival to be good. In artificially fertilizing eggs, mature females are caught and the eggs are carefully squeezed out into a pan of water. Sperms from the males are removed in the same way and placed in the pan with the eggs. The eggs and sperms are carefully stirred to insure a large per cent of fertilization. The adult fish are then put back into the water or are used for food. The fertilized eggs are placed in tanks of running water until the young hatch and get well started in their development. They may then be shipped and placed in streams and lakes (Fig. 339).

Other water life. Oyster-fishing is one of the most important industries of the Atlantic coast. Formerly these mollusks were so plentiful that it seemed that the oyster beds could never be exhausted. About 1920 there was a marked decline in the oyster crop in most parts of the world. The causes were mainly overfishing, pollution of the water, and the failure of the young to start, or "set," either because too many were caught by enemies or because they could not find suitable beds to which to attach themselves. Oysters are now protected and cultivated. They are

artificially propagated somewhat as fish are. The young oysters are kept in protected places until they have passed the free-swimming larval stage. Then, if suitable beds of rock, shells, or twigs are provided, they will attach themselves in great numbers. When they are about the size of a quarter they may be moved to other beds where they will not be so crowded and will grow more rapidly and become larger.

Clams are protected in many places by closed seasons lasting several months of the year. Some success has been achieved in introducing desirable species of clams into waters where they are not naturally found.

Lobsters are also grown in hatcheries, then planted in favorable waters. The lobster industry is further protected by laws to prevent the taking of lobsters which are too small to be of much value commercially.

***Summary of methods of wild-life conservation.** We have considered several ways of conserving wild life. (1) Laws have been passed by both state and Federal governments to provide closed seasons, limit the number of animals which can be killed, and prohibit destructive methods of hunting or fishing. (2) Sanctuaries, parks, and reserves have been established by Federal and state governments and by individuals. (3) Provision is being made for the increase of wild life through artificial propagation, restocking of streams and woods, providing food in winter, controlling enemies, and other related means of protection. (4) Such organizations as the Bureau of Biological Survey, the Forest Service, and the Bureau of Fisheries are rendering valuable service in many ways. Their investigations of the food of certain animals provide a basis for determining whether these animals are useful or harmful and for constructing a program for conserving useful kinds. The studies of the habits of breeding and of migration help to form a basis for laws regarding hunting and trapping. Studies of diseases and pests which harm desired plants and animals are valuable aids in the conservation of wild life.

Self-test on Problem XXVI–F. 1. *All* food fish are protected by law during their spawning seasons.

2. A *fish* which is very valuable as food is the oyster.

3. State four ways in which wild life is conserved.

4. Fish and other water animals are conserved chiefly because of their value as a source of *pearls*.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. What is a forest community?

2. In what ways is the balance of life affected by cutting and burning over the forest, including the farm wood lot?

3. How is the forest a factor in the use of the leisure time which shortened work periods permit?

4. In what ways could changed use of now idle or low-value lands in your region promote recreational and financial welfare?

5. How does a forester produce the maximum quantity of logs which will produce lumber without knots?

6. List the direct and indirect ways in which forests affect the comfort of people.

7. Why are certain kinds of trees found together in plant societies?

8. Birds usually feed on whatever food materials are most abundant at the time. Of what particular value to man is this feeding habit?

9. During the nesting season birds probably are of more value to man than at any other time of the year. Why?

10. Can you explain how biological surveys could be made to serve as the basis for legislation in regard to wild life?

11. What more than this chapter suggests can the individual do for the protection and care of birds?

12. In what way does migration play an important part in conservation of fish?

Exercise on Scientific Method (Making Inferences). Small mammals need to eat a far greater proportion of their weight than do the large mammals. How many reasons to account for this fact can you suggest?

Special Reports. 1. Discuss the history of the use of the forests and lands of your locality, your state or province, or your country.

2. What are the most destructive insect pests of your vicinity? Do birds feed on these insects? If so, what birds?

3. Salt Lake City has erected a statue of the sea gull because of the help these birds gave in combating a grasshopper plague. Report more fully on this story.

4. What bird refuges or sanctuaries are there in your state?

5. What animals are protected in your state? For which animals are there brief hunting seasons? Are there any animals that are not protected which you think should be? Are there any harmful animals which should be destroyed? (Consult your state department of conservation.)

6. What birds once abundant in your state have decreased greatly in numbers? What factors help to account for their disappearance? Look in an encyclopedia or a book on birds under *egret*, *passenger pigeon*, and *golden plover*.

7. Write to the United States Department of Agriculture for the annual pamphlet containing a summary of the laws relating to hunting seasons.

8. How is paper made? What forest products other than those named on page 510 can you list? What is celluloid? excelsior?

9. Find out as much as you can about the biological explorations of William Beebe, Martin Johnson, Carl Akeley, John Ernest Williamson, and Roy Chapman Andrews. (*Who's Who in America* will give you some information and will direct you where to look for more.)

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Chapter XXVII · Conservation and the National Parks

Questions this Chapter Answers

Why are certain regions kept in their wild condition?

What is a national park?

What biological interests are characteristic of national parks?

How many and where are the national parks of the United States and of Canada?

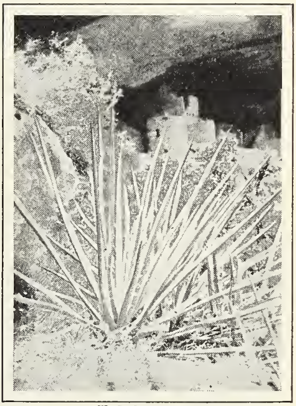
What are the special features of the two parks used as types?

In what ways is knowledge of biology related to enjoyment of national parks?

In what ways do visits to the national parks contribute to the use of biological knowledge?

Problem XXVII–A · Why and How are National Parks Provided?

Keeping wild regions and wild life. There are regions possessing peculiar features which, if once destroyed, cannot be reproduced (Fig. 340). Such are Niagara Falls, the Florida Everglades, the Okefenokee Swamp, the Yosemite Falls, the redwood and big-tree forests, the Yellowstone region, the great mountain forests, and many others. The United States and Canada, some of the states, and a few individual citizens have undertaken to save some of these regions in which natural features and native wild life may be kept. Some of these provide illustrations of the most wonderful surface features of the earth, as well as the



U. S. Department of the Interior

Fig. 340. Spanish bayonet and old cliff dwellings, Mesa Verde National Park. Can you decide what kind of climate this region has from the appearance of the plant?

FIG. 341. How do you account for the fact that so many of the parks are in the western part of the country?

natural homes of many kinds of wild life. This policy of saving these regions and the animals and plants within them has developed as one of the services of the Department of the Interior. Public-spirited citizens have been highly important factors in securing for the government some of the unique natural regions now included in national parks. There are twenty-two national parks in the United States and eighteen in Canada (Fig. 341). There are also many national monuments and state parks. In general the monuments include the locations of noted historical occurrences, while the parks include unusual natural features. Each of these regions has its own peculiar surface features, and to some extent its own types of wild life.

In this chapter we shall briefly discuss only two national parks. The discussion of these two will suggest biological problems which may be studied in any of the parks.

Self-test on Problem XXVII–A. 1. The national parks of Canada and of the United States are under the control of the *Department of Agriculture.*

2. The United States has only *six* more national parks than has Canada.

3. National parks are important as a means of *preserving* wild life and *conserving* natural beauty.

4. There are *three* national parks belonging to the United States which are not in the United States.

Problem XXVII–B · What are Some of the Special Features of the Yellowstone National Park?

Location and general features. Almost all of Yellowstone National Park is located in northwestern Wyoming. It extends slightly into Montana and Idaho. In ancient times there were volcanoes out of which materials were poured upon the whole surrounding country. There are no active volcanoes now in this park, but many evidences still remain to show the volcanic[1] nature of the region. For example, an old crater[2] is located near Mount Washburn in this park. There is a cliff made of black

[1] *Volcanic* (vol kan'ik): having to do with a volcano.

[2] *Crater* (kra'ter): the mouth of a volcano.

volcanic glass (obsidian). There are forest trees which were buried and in which the tissues of the wood were replaced by silicon.[1] These fossil trees consist of almost pure glass, since glass is made partly of silicon. There are active geysers,[2] some of which throw out hot water in which various earth materials are dissolved. By study of these and many other features scientists have definitely proved the volcanic origin of part of the Yellowstone National Park. There are also evidences that much of its soil has been deposited by glaciers and rivers.

A. M. N. H.

FIG. 342. Tree at timber line. What evidences do you see of the struggle for existence? What factors make this struggle severe?

The ancient trees. The fossil forests tell many things about the earlier history of Yellowstone National Park. By a study of magnified cross sections of the fossil wood it has been learned that at least part of the forests were composed of trees somewhat like our modern pines, redwoods, big trees, and some other evergreen trees. The rate at which such trees grow makes it fairly certain that some of these ancient trees were two hundred to three hundred years old when they were buried. Also, the fact that different fossil forests, one following another, extend throughout at least two thousand feet of rock shows that several such forests were buried at different times. Many thousand years were involved in the total period of life of all these forests.

It is thought that, after a forest had grown, a volcanic outburst buried it. The period of volcanic action lasted a long time. The trees were entirely buried by melted rock, ashes, mud, and other materials. Long periods followed when no volcanic action oc-

[1] *Silicon* (sil′i kon): the element which combines with oxygen to form quartz and certain kinds of sand.

[2] *Geyser* (gi′zer): a deep spring from which water or steam is sent forth at intervals.

curred. During these periods new forests grew. These in turn were buried during the next volcanic period. It is thought that at least twelve such forests were buried.

Elevations and life zones. The park lies at an elevation between one and two miles above sea level. This range in elevation provides conditions for many kinds of plants (Fig. 342) and animals. The changes in altitude are accompanied by changes in light, moisture, temperature, air, and wind. The elevations have been grouped into five zones, to each of which a special name has been given. A study of the accompanying table will give help in understanding the biological problems of this park.

Height above Sea Level		Square Miles	Per Cent of the Entire Park
Upper Sonoran	Below 5500 . .	Continuous with surround	ing country
Transition	5500–6000 . . .	19	0.6
	6000–6500 . . .	92	2.8
Canadian	6500–7000 . . .	196	5.8
	7000–7500 . . .	425	12.7
	7500–8000 . . .	1120	33.4
Hudsonian	8000–8500 . . .	824	24.6
	8500–9000 . . .	428	12.8
Arctic	9000–9500 . . .	153	4.6
	above 9500 . .	91	2.7
		3348	100.0

These zones grade into one another, and some of the plants and many of the animals that are found in one zone often appear to some extent in the preceding or succeeding zone. Due to the more severe winds from the northeasterly direction, there is usually a difference of several hundred feet or even of a thousand feet between the upper limits of the zones on the northeast slopes and those on the southwest slopes. In the lowest parts of the park, that is, in the Upper Sonoran zone, plants and animals are found which are characteristic of the lower lands not included in the park to any considerable extent.

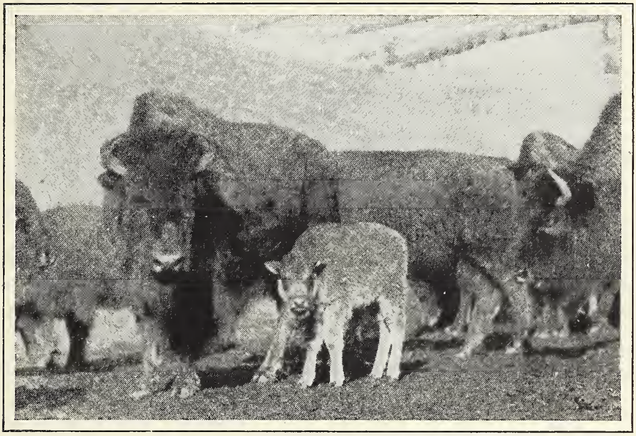
Trees typical of different elevations. A noted naturalist, John Muir, once said of the Yosemite National Park, " A traveler may determine his elevation within a few hundred feet by the trees

alone." He referred to the fact that in general the trees and the other plants of mountainous parks are characteristic for each zone of elevation. Such a statement as he made, however, could be true only of a well-informed traveler. In most cases trees do not grow above 9500 feet to 10,000 feet. The upper limit of tree growth is called the timber line. On slopes which have more moisture and less exposure to heavy winds and ravines, trees are found at higher altitudes. The timber line therefore varies somewhat in elevation. The same kind of tree may have very different form and appearance, depending on whether it has grown in a lower zone or near the timber line in the Arctic zone.

Animals typical of different elevations. The distribution of animals in different zones is unlike that of plants in certain very important ways. Plants either grow or fail to live in the particular places where their seeds chance to start their growth. If, for example, the seeds of the lodgepole pine fall on the rocky soil of the Alpine zone, above the Arctic, they cannot produce successful trees. Many of the animals, however, can move from one region to another and thus may find places in which they can live. Then some of the animals which depend upon plants for their food may go to the regions in which they may find the kinds of plants they like best. Those animals which feed upon animals follow their prey from zone to zone. Thus the animals of the Yellowstone National Park move into upper zones as the vegetation of spring and summer develops, and move downward again as vegetation declines and as the severe weather of autumn and winter comes.

Large mammals of Yellowstone Park. The 3348 square miles in the park by no means include all the area over which the wild animals of the park may range. Joining the park are extensive forests and grasslands and the untimbered higher mountain ranges. These together make an area several times that included in the park. According to existing game laws the animals may be hunted outside the park. Within the park it is unlawful to hunt them. It frequently occurs, when feed is insufficient, that wild animals travel long distances and may enter the park or leave it in their search for food.

The American buffalo, or bison, is one of the most interesting of all the larger wild animals. Herds of these animals were so useful to the Indians that some of the tribes followed and camped



W. J. Mead, Yellowstone National Park

FIG. 343. This buffalo calf was born in the late fall. Would its struggle for survival, therefore, be more or less severe than if it had been born in the spring?

near the herds for months. The buffalo meat, both fresh and dried, served as food; the skins made excellent clothing and robes; the bones and horns were used for needles, spear heads, ornaments, and other articles. It was one of the Indian's greatest hardships to have the buffaloes driven from their native plains.

The buffalo bulls are powerful animals, sometimes weighing as much as a ton or more. Their peculiar heavy shoulders, powerful muscles, heavy necks, short sharp horns, heavy skulls, and deep-set eyes fit them for terrific combat. In spite of being thus equipped for fighting, buffaloes are easily stampeded[1] when frightened. Indians sometimes killed large numbers of buffaloes by stampeding them and causing them to run over high banks.

Buffalo calves are usually born in late spring at a time when fresh grass enables the cows to produce milk for their offspring (Fig. 343). Even under most favorable conditions, however, the amount of milk produced is usually not large; the calves must, therefore, soon learn to secure part of their food by eating grass.

[1] *Stampede* (stam peed′): to run away in fright and disorder, as when horses, cattle, or hogs run in a herd without regard to their safety.

The calves usually remain with their mothers most of the time until they are six or seven months old, and usually continue in the same herd with their mothers until almost or fully grown.

FIG. 344. Moose, Elk Island National Park, Canada. Why is it necessary to protect these animals?

The antelope, or pronghorn, is one of the swiftest members of the whole deerlike tribe. In spite of that fact these animals were so reduced by wolves and other enemies, including men, that two decades ago there was danger that the species would become extinct. The protection recently given them, together with the destruction of predatory[1] animals, under supervision of the park authorities, the United States Biological Survey, and the United States Forest Service has given antelopes a new lease of life. Hundreds of antelopes now range the park and some of the adjacent country.

In the upper valleys of the Yellowstone National Park and in high valleys outside the park there are several thousand moose. These large animals, called Shiras' moose,[2] are somewhat smaller and darker in color than the moose of northeastern United States and of Canada (Fig. 344). The differences are not marked, however. Moose live in dense woods and along the margins of upland swamps. They eat willows, bark of the softwood poplars, small shrubs, and water plants. Moose are not commonly observed by park visitors, since their usual ranges are far from the roads and trails.

The white-tailed deer, mule deer, and elk (see Fig. 276, p. 421) are fairly abundant in the park. In some years they are so numerous that they range into the surrounding regions in which domesticated cattle and sheep are grown. The elk gather in a

[1] *Predatory* (pred'a to ry): living by prey.

[2] Named in honor of the noted American naturalist George Shiras III.

Fig. 345. Bighorn sheep, Rocky Mountain National Park.[1] Special Report: Compare the Rocky Mountain sheep with the Rocky Mountain goat. Consult bulletins from the Bureau of National Parks

large herd and move slowly over their grazing region, proving a real menace to a farmer's pasture lands. The deer travel in smaller numbers, move more rapidly, and are rarely a real problem to the neighboring farmer.

The Rocky Mountain sheep (Fig. 345), distantly related to our woolly domestic sheep, are among the most picturesque of all wild animals. Extremely wild, ranging among the highest rocks, picking grass and shrubs from places where few other animals go, they are frequently sought but seldom seen by nature enthusiasts. Their bulging eyes are adapted to catch the view of a possible enemy — a man, a coyote, a wolf, a bobcat, or a Canada lynx. Their strong muscles and sharp hoofs enable them to run rapidly and safely over rocky cliffs upon which most other animals would not venture. In spite of their heavy curved horns adapted for combat, the males seek safety in flight. In fact, when they must fight their enemies at close range, they chiefly use the hoofs of the front feet. During the mating season in the autumn there are small bands, each consisting of three to six females headed by a valiant and usually old male, with the rest of the males scattered singly, each trying to wrest the leadership of the band from the

[1]Photograph by Clark Bleckensderfer. Used by permission of the Denver Association.

male which heads it. After this autumn breeding season the sheep may gather in larger herds, though usually the males travel in separate groups. The lambs are born in late spring and are guarded as well as can be by the mothers, but many are killed and eaten by the enemies which are a never-ending source of fear to these wild sheep.

The predatory animals are in striking contrast to the mammals already described. These are the bears (grizzly and black), mountain lion, Canada lynx, bobcat, wolf, and coyote. Each of these animals has its own peculiar habits of living, but they are alike in that all prey upon the young and sometimes the adults of the preceding groups of mammals. A male grizzly bear or a large brown bear can kill even the largest buffalo or elk if he can succeed in striking it with the full force of his powerful paw. The mountain lion or the lynx may drop from a ledge of rock or a limb of a tree upon a deer or a sheep. The wolves and coyotes regularly hunt the young of all the large mammals and, combining into hunting bands or packs, pursue and often catch full-grown animals. In the Yellowstone National Park, sometimes for weeks, bands of wolves with their own young may follow herds of elk or buffalo in order to make sure of a supply of fresh food. Such predatory animals are a source of constant danger not only to buffalo, deer, elk, and sheep but also to domestic animals. They are an important factor in the everlasting struggle for existence and the resulting balance of life.

Each of these animals has individual habits and ways of caring for its offspring that are quite as interesting as are those of the animals commonly regarded as more useful. For example, the black bears will eat almost anything available, such as mice, chipmunks, squirrels, woodchucks, fish, lizards, insects, and almost all kinds of plants. They will enter the campers' tents or automobiles and do not disdain anything that human beings will eat. In late autumn, when they are fat, the approaching winter drives them into hibernation. The females which are to produce young hibernate earliest. The young bear cubs, born during the winter, are very small and incompletely developed when born, and remain with their mothers in their dens for two months or more. Then as spring comes mother and cubs emerge, the mothers now poor.

Fig. 346. How many economic values of the muskrat can you name?

Bear cubs usually remain with their mothers until a year and a half old or more. Female black bears produce young every two years; grizzly bears, every three years. Bears are said to live to be thirty years old.

Small animals of the park. Many kinds of small animals live in the park. There are flying squirrels, which sail from higher to lower places in the trees by means of extensions of the skin which are stretched from forelegs to hind legs. There are red pine squirrels, which bury bushels of nuts and seeds for their winter food. There are several kinds of chipmunks, ground squirrels, and mice, each with an interesting story for the naturalist who will observe quietly and long. Muskrats (Fig. 346) build their homes along the swamps and pools, and beavers build theirs across the mountain streams. The porcupine (Fig. 347) makes its home under rocks and logs, in brush piles, or in tops of fallen trees, and has a covering of sharp quills which cause painful and prolonged regret to any inexperienced dog, wolf, or boy who takes hold of the animal.

The streams and lakes have many kinds of fish. There are harmless snakes, the harmful ones having been greatly reduced in number. The bushes and trees provide homes for many kinds of birds. The bald eagle and less frequently the golden eagle come into the park in the summer time and are a source of danger to the young of such animals as deer, elk, and sheep. Hawks are more abundant, and exact their large toll of smaller birds, fish, and small mammals.

Wild animals are wild. Many people who visit the national parks do not understand wild animals. These animals have been

protected until they are usually unafraid of human beings. Since the animals do not run away, some people conclude that it is safe to treat them as if they were as tame and harmless as cows and dogs. Visitors may feed deer and bears, but should always be watchful. A bear may strike the person who feeds him, if anything occurs to stimulate the bear to his natural actions. Gratitude and respect for the hand that feeds him are not usually developed in the bear. The male deer may eat an apple from a visitor's hand, then stand and strike out with his sharp hoof at the visitor if in any way dissatisfied with his treatment. Each year several park visitors must be given medical or surgical treatment for injuries given them by park animals. Such animals are quite harmless to all who respect the fact that they are really wild animals which have learned that men do not wish to destroy them.

B. M. McKee

FIG. 347. Porcupine, Grand Canyon National Park, Arizona. The porcupine is found in various parts of the United States and Canada. What advantages does the animal derive from being able to climb trees?

Self-test on Problem XXVII–B. 1. Yellowstone National Park is located in a *volcanic* region.

2. All of Yellowstone National Park is more than (1) one; (2) two; (3) three; (4) one and one-half; (5) one and one-quarter miles above sea level.

3. In general the animal life is *more* closely confined to certain zones of elevation than is the plant life.

4. The many buried forests in the park prove that this region is *comparatively young.*

5. Wild-animal life in the park is protected during *part* of the year.

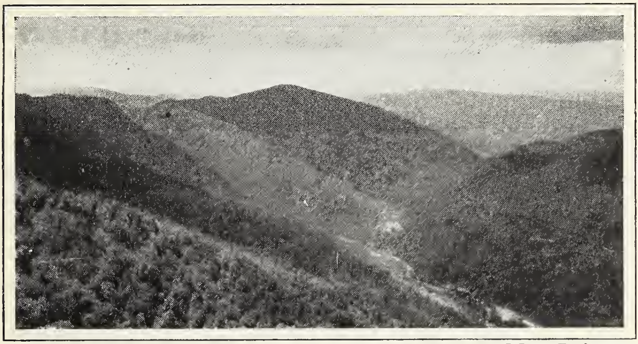


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Fig. 348. Great Smoky Mountains National Park. Why are there trees at all elevations in these mountains while there are none on the tops of the mountains in Yellowstone National Park?

Problem XXVII–C · What are Some of the Features of the Great Smoky Mountains National Park?

General features. The Great Smoky Mountains National Park presents a striking contrast to the Yellowstone National Park. While most interesting and picturesque, it also possesses qualities much like those of almost any hilly or mountainous region anywhere in the eastern half of the United States. These common features exist, however, in such magnitude[1] and grandeur[2] as to give this park a distinction all its own (Fig. 348).

The Great Smoky Mountains National Park is located in the eastern part of Tennessee and the western part of North Carolina. It is a part of the Appalachian Mountain region. It includes wide and long valleys between its mountains. The Appalachian Mountains are very much older than the Rocky Mountains, to which the Yellowstone National Park region belongs. The Appalachian Mountain peaks have been worn down by weathering and erosion, until some geologists[3] say that the mountains now seen in the

[1] *Magnitude* (mag′ni tude): great size.

[2] *Grandeur* (gran′dyure): state of being grand or majestic.

[3] *Geologist* (je ol′o jist): a scientist who studies rocks and rock formations.

Great Smoky Mountains National Park are the big bases of those that used to be there. A few remaining mountain peaks exceed 6000 feet in height, but most are much lower. Alluvial[1] deposits by the streams have built deep beds of rich soil in the valleys.

No doubt the higher mountains of ancient days were topped by rock upon which scanty vegetation and animal life could exist. At the present time forest trees and many other kinds of plant as well as animal life thrive even on the tops of these mountains. Therefore these mountains present a very different appearance from that of the exposed, treeless, rocky tops of the mountains in and about the Yellowstone National Park.

Living things aid in making new mountains into old. Usually, when rock has been exposed for a few years, not only the nonliving but also the living agents of weathering and erosion start the process of breaking up the rock's surface. Within a few years perennial woody plants, that is, the shrubs and trees, gain a foothold (Fig. 349). Wherever plants grow, animals appear sooner or later.

The forests of the Great Smoky Mountains National Park, the valley meadows, the streams, lakes, and steep rocky cliffs present many different chapters in nature's energy-story. These chapters change as the seasons and years advance, so that one who once has read the chapters may read their still more fascinating changes in later years.

Numbers and kinds of trees. There is no record of any other national park which contains so many kinds of forest trees and shrubs. One hundred fifty-two kinds have been listed. These include pines, spruces, firs, cedars, and cypresses, though most are deciduous trees and shrubs. The depth of soil and the moisture conditions have favored the maximum growth of the individual trees of these forests.

The tulip tree. In some respects the most striking tree of this park is the tulip tree, commonly called yellow poplar or whitewood, although neither a tulip nor a poplar. It takes the name tulip from the form and size of its very fragrant and beautifully colored flowers, which resemble tulip flowers in form. The tree belongs to the magnolia family.

[1] *Alluvial* (al lyu'vi al): deposited by water.

Colorado Association

FIG. 349. Biological succession, Rocky Mountain National Park. Gradually the evergreens will take the places of the deciduous trees (aspens). Can you suggest reasons to account for this statement?

Such a tree began its life some three hundred to four hundred years ago. It has been securing and using energy during the Pilgrims' voyages and settlements, the Indian wars, the discovery and settlement of North Carolina, Tennessee, and the rest of the United States, the Revolutionary War, the Civil War, the development of our whole program of education, the building of all the railroads, the World War,— in fact, during the time of all our accomplishments in America.

Animal and plant zones. The life zones are less clearly marked in old and lower mountain regions than they are in such newer and higher regions as the Yellowstone National Park. Also, the extension of plant and animal life up and down the older and more gradual slopes of the Great Smoky Mountains makes the life zones less distinct at different elevations. So far as concerns the plant life, it is possible to find, from the lowest to the highest elevations almost all the species which one would find from the lowlands of the Southern states (Fig. 350) to the boundaries of Canada. That is, the tops of the highest park mountains have vegetation resembling that of the elevations of eastern Canada. The animals tend to range over all the elevations of the park.

National Park Service

Fig. 350. Southern pines, Hot Springs National Park, Arkansas. What reasons can you suggest for preserving such a location as this?

From 1000 to 1200 feet above sea level there are the overgrown fields of former farm lands, of which the cedar woodlands are the most conspicuous features. Hundreds of kinds of flowering plants and such animals as rabbits, woodchucks, skunks, mice, rats, and snakes are found in this zone. At higher elevations such trees as hickory, chestnut, and oak are dominant. Animals found in this region include red and gray foxes, the raccoon, the mink, the deer, the wild turkey, and occasionally the wolf and the black bear.

At the highest elevations spruces, firs, and rhododendrons are abundant; also heaths, consisting of low shrubby growths resembling those of northeastern United States and Canada. Bears, wolves, beavers, otters, rattlesnakes, and copperhead snakes thrive in and about the heaths and upland forests.

National Park Service

FIG. 351. Wild morning-glory (*Datura meteloidea*), Zion National Park, Utah. What other types of plants should you expect to find growing in a similar location?

Many kinds of living things. At least two hundred eighty species of birds are known to nest in the park. Birds now becoming rare are the golden eagle, the wild turkey, the great blue heron, and the whistling swan. There are at least sixty species of wild vertebrate animals besides the birds. Not less than a hundred species of fish are known to inhabit the waters of the park. The insects have not been fully studied, but the number of species of insects surely reaches several thousand. Certainly two thousand and possibly more species of flowering plants live in this park. Ferns, liverworts, mosses, algæ, fungi, lichens, and bacteria in unknown numbers find their ideal home in the varied and favorable locations the park provides.

Whose are the parks? The national parks were established by the Department of the Interior and are managed by it for the benefit of all citizens. The roadways, camps, hotels, and information services are available to all. Unusual features are maintained in as close to primitive conditions as is possible (Fig. 351). Trained guides and instructors, printed descriptions, and explanations of important features are available. Large numbers of people use the national parks. Some of these visit the parks wholly for recreation (Fig. 352). Others seek opportunities for making scientific studies of the various features of the parks. There is usually no

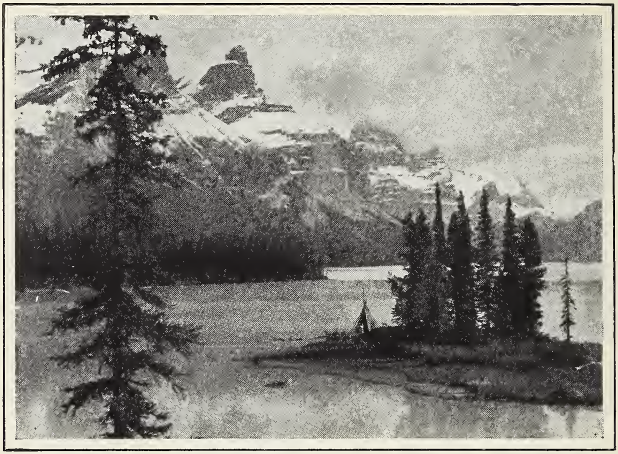

Fig. 352. Maligne Lake, Jasper National Park, Canada. What kinds of wild life should you expect to inhabit this region?

aspect of the parks more attractive than the living things within them. This chapter is only an outline of some biological features of two national parks, but it will serve as a beginning for a really thoughtful biological traveler.

Self-test on Problem XXVII–C. 1. Great Smoky Mountains National Park is located in *Wyoming* and *Montana.*

2. The mountains of this park are *somewhat younger* than those of Yellowstone National Park.

3. Yellowstone National Park is especially noted for its (1) falls; (2) numerous glaciers; (3) geysers; (4) snow peaks; (5) plant life; (6) extinct volcanoes; (7) lake.

4. The plant and animal zones are *more clearly* marked in Great Smoky Mountains National Park than in Yellowstone National Park.

5. National parks are important in the conservation chiefly of __(?)__.

6. National parks are valuable as places for study and __(?)__.

Special Reports. 1. Secure from the United States Department of the Interior the available publications and conduct a class discussion of the

biological features of the national park which is (1) nearest to your school, or (2) farthest from your school, or (3) the one you think is likely to be most unlike the region in which you live.

2. Secure from the United States Biological Survey reports on efforts to control desired and undesired animals of the national parks, and conduct a class discussion of (1) park animals which are in danger of being exterminated, or (2) park animals which are in danger of becoming too abundant, or (3) methods of control of predatory animals in the parks.

Reference Books

These are but a few of many publications dealing with the Yellowstone National Park:

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Unit VIII · *The Struggle for Energy through Succeeding Generations*

PROBLEMS DISCUSSED IN THIS UNIT

The problems of reproduction and inheritance are among the most fascinating and baffling in the entire field of biology. Scientists eagerly search in all parts of the earth for facts related to these problems. They observe animals and plants wherever these can be found. They invent and perform countless experiments, but the problems cannot be solved solely by observations of organisms now living. Perhaps the rock picked up by a geologist on a hilltop which was once part of the bed of an ancient ocean may contribute a small bit to the solution. Every fact established is carefully fitted into its place. Slowly, as the result of careful investigation, knowledge takes the place of ignorance. Bit by bit, like all other scientific problems, those dealing with life and its continuance on the earth are approaching solution.

This unit is devoted to a discussion of these major questions of reproduction and inheritance:

- Can living things be produced from nonliving things?
- What are the various ways in which living things, from the simplest to the most complex, reproduce their kinds?
- What light do the known facts about reproduction throw upon the struggle for existence?
- How and why do living things change from age to age?
- How can man use his knowledge of the laws of reproduction and inheritance to improve plants and animals?
- How are things that are now living related to the things that lived in the past?

Chapter XXVIII · The Simplest Kinds of Reproduction

Questions this Chapter Answers

What have been some of the most important theories regarding how life originated[1]?
What were the most important steps in the overthrow of the theory of spontaneous generation?
What are the differences between growth and reproduction?
Why is it necessary that plants and animals make provision for reproducing themselves?
May the same kind of plant or animal use more than one method of reproduction?
What is reproduction by fission? by budding? by asexual spores? by regeneration?
What plants and animals illustrate each of these four methods of reproduction?
What practical uses have men learned to make of any of these methods of reproduction?

Problem XXVIII–A · Can Life Start from Dead Material?

Life from preceding life. From earliest times people have tried to reason out and explain when, where, and how life first appeared upon the earth. We do not yet know. There have been many theories[2] and beliefs concerning the origin of life. The earliest belief is found in some form or other in the folk tales of Indians and of many other primitive peoples. They believed that when conditions upon the earth became favorable the various living things suddenly appeared exactly as we now know them. This belief was not based upon scientific observation or investigation of any sort and hence was rejected long ago.

A later belief that was accepted by many people through nearly all of history was based upon the "theory of spontaneous[3] genera-

[1] *Originate* (o rij′i nate): to start, or to produce first, or to create.
[2] *Theory* (the′o ry): an attempt to explain phenomena or happenings of any sort.
[3] *Spontaneous* (spon ta′ne us): acting alone and with no outside influences, that is, acting entirely from inner impulses or causes.

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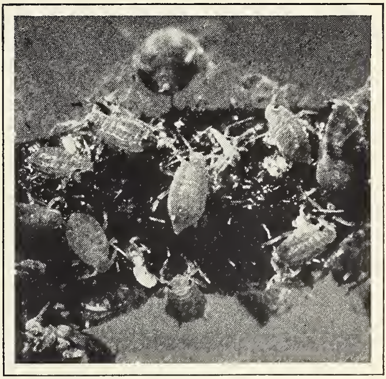
FIG. 353. Toads and frogs were once supposed to originate, under the influence of sunshine, directly from the mud in the bottoms of ponds. What other such unfounded beliefs have you heard? (The toad on the right is croaking)

tion."[1] According to this theory, under favorable circumstances dead organic material and even inorganic material may become alive. This theory seemed scientific since it was based upon a considerable number of observations, though these observations were neither complete nor accurate. The writings of many noted men of ancient and of even fairly recent times not only supported the belief in spontaneous generation but gave many examples which the writers thought proved its truth (Fig. 353). For example, Aristotle (384–322 B.C.), one of the greatest men of all times, stated that mice are generated in a spontaneous way from old rags that have been packed in boxes and placed in dark warm places. Van Helmont (1578–1644), who about nineteen hundred years after Aristotle's time was a student of the chemistry of living things, published instructions for producing scorpions and mice spontaneously. Another scientist (Buffon, 1707–1788) said that worms may be caused to develop spontaneously by putting together the hollow sides of two pieces of building brick, provided crushed wood and oil have been placed first in one of the hollows of the brick. And still later Alexander Ross (1590–1654) wrote thus about Sir Thomas Browne, who had expressed doubt about

[1] *Generate* (jen′er ate): to begin or start new. *Generation* (jen er a′shun), the process of generating or starting something; usually refers to starting new plants and animals.

whether "butterflies, locusts, grasshoppers, shellfish, snails, eels, and such like" are produced from decaying matter: "To question this is to question reason, sense, and experience. If he doubts this, let him go to Egypt, and there he will find the fields swarming with mice begot of the mud of the Nile, to the great calamity of the inhabitants."

Until a few decades ago it was not uncommon for people who saw mosquitoes and other insects arising from the surface of stagnant water to cite these observations as illustrations of spontaneous generation of living things (Fig. 354). During the childhood of many persons now living the belief was common that the living things which cause spoiling and decay in such liquids as sirup, soups, and the stagnant water of outdoor pools are developed by spontaneous generation. In fact it was generally believed, and still is in some countries, that any organic matter which has favorable temperature and proper moisture may be the scene of spontaneous generation of living things.



Cornelia Clarke

FIG. 354. Plant lice on a stem (greatly enlarged). Aristotle taught as an observed fact that plant lice rise from dew. Can you explain how someone might make this inaccurate observation?

Redi's famous experiment. The first important step toward the overthrow of the theory of spontaneous generation resulted from experiments by Redi (1626–1698), an early Italian scientist. Redi doubted the common claim that fly larvæ are spontaneously produced in meat. His theory was that the larvæ develop in meat only if flies are allowed to come in contact with it. It must be remembered that the life history of flies was not then known.

To test his theory Redi devised this experiment: He first cooked meat in order to be certain that nothing remained alive

in it. He then placed some pieces in each of three glass flasks. One he left uncovered, one he covered with gauze, and the third

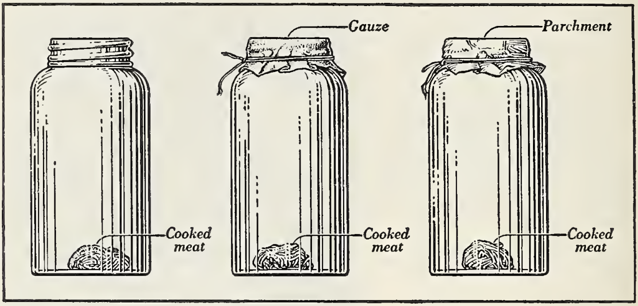


Fig. 355. Redi's experiment. Exercise on Scientific Method (Using Controls): Which of these jars served as controls? Explain

with parchment. Flies could enter only the first flask (Fig. 355). Maggots appeared in the meat in that flask. Flies laid their eggs on the gauze cover of the second flask, where they hatched into larvæ, or maggots. The meat became putrid, or rotten, in both covered jars, but no maggots appeared in the meat in either of the covered flasks.

Redi's experiment proved that, in so far as meat is concerned, larvæ do not generate in it spontaneously and that reproduction of flies depends on the laying of eggs by parent flies. It also stimulated studies of the life cycles of insects. But the most important result was in contributing evidence which helped to show that new living things come only from those already living.

Pasteur and spontaneous generation. Redi's experiments did not, however, result in the overthrow of the theory of spontaneous generation. During the next two centuries the controversy continued. From time to time noted scientists performed experiments, the results of which they interpreted as favoring one side of the controversy or the other. The invention of the microscope, the discovery of oxygen, the discovery of the causes of fermentation, and other scientific discoveries raised new objections which had to be removed, or which helped to remove older objections.

In the great mass of evidence produced, however, the contributions of two men, Pasteur and Tyndall, deserve special mention.

A number of experiments by various men seemed to prove that infusions[1] in which all living organisms have been killed by heating remain unspoiled if no air is admitted to them except that in which all microörganisms are killed by heating. Yet such experiments did not remove all the objections raised by the critics. Pasteur therefore designed a special flask (Fig. 356). After putting an infusion in the flask he boiled it, then by heating the neck of the flask drew it out into a curved neck having a small opening. No dust could then enter the flask and reach the infusion, because it would settle on the surface of the curved neck.

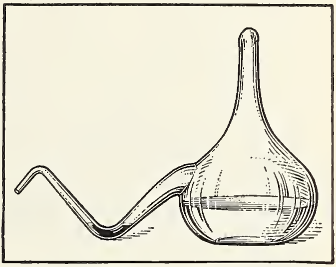


FIG. 356. Pasteur's flask. In what respects did this experiment mark an improvement over the experiment by Redi?

No microscopic life developed in the liquids so treated. Pasteur therefore claimed that his experiment proved the theory of spontaneous generation to be false. Some of the chemists claimed, however, that boiling had caused changes in the liquids, with the result that after being boiled they would not support life. Pasteur then broke open the mouths of some of the flasks in which there was broth that had been boiled, thus permitting air to enter. Soon the liquid became filled with microscopic living things. This result proved that, after having been exposed to the air, the boiled liquids would support life. But, more important than that, it proved that the living things came in with the air that entered the broken flasks.

Experiment 85. What results will you obtain from repeating some of the early experiments with infusions? Prepare an infusion made of water and beef, dried grass, any packing material, or commercial beef broth. Sterilize the liquid by boiling it for ten minutes. Then place a small amount of the liquid in each of eight flasks or large test tubes. Keep

[1] *Infusion* (in fu'zhun): a broth made by boiling meat or other nutritious substance in water.

half of the flasks or tubes closed with plugs of cotton which has been sterilized. Place one open and one closed tube side by side for twenty minutes in the school hallway; place another pair out of doors, and a third pair in the schoolroom. Dip your lead pencil into the liquid in the open tube of a fourth pair. Mark the open flasks so that you can readily identify them, then stopper all the flasks with cotton and keep them in a warm dark place. After two or three days examine the pairs of tubes. What difference do you find between the infusions in the tubes which have been kept stoppered and those which were opened? Do these results agree with the evidence of Redi and Pasteur? Explain.

Exercise on scientific method (using controls). What were the controls in the four parts of this experiment? Why were they necessary?

Pasteur's experiments thus added important evidence against spontaneous generation and in favor of the claim that new life, even among microscopic forms, comes from life that already exists. These and other experiments also proved that the air may be a means of carrying the smallest kinds of living things. Pasteur later found that an ordinary glass flask or a test tube, when closed by a cotton plug, made a satisfactory substitute for the special flask he had used in his earlier experiments. The cotton plug keeps out the dust and small organisms carried by the air, and allows the passage of oxygen and other gases.

Tyndall's experiments. Experimenting further on spontaneous generation, John Tyndall, an English scientist (1820–1893), made an apparatus (Fig. 357) by means of which to make sure whether the air carried the living things into the beef broth, as Pasteur and his associates claimed, or whether they originated within the broth, as Needham and his followers claimed. Tyndall's apparatus made it possible (1) to take out of the air all dust particles and therefore all living things; (2) to allow this dust-free air to reach the beef broth in open test tubes; (3) to observe the broth from day to day without handling it.

Tyndall announced in 1876 that no living things developed in the beef broth that was tested in this new apparatus. His evidence was sufficient to complete the overthrow of the theory of spontaneous generation. All scientists now believe that life is produced from life, that is, that living things can only be the descendants of other similar living things.

We are not likely to estimate too highly the importance of the experiments by Tyndall, Pasteur, and others, and of the facts established by them. One immediate result was Lister's proof that infection of surgical wounds can be prevented.

With the claims of spontaneous generation disproved, a new and strong stimulus was given to efforts to learn just how living things are reproduced.[1] Much was then known about reproduction among some of the higher plants and animals, but not much was known about life cycles of lower forms of life. Even today the life cycles of many living things are unknown.

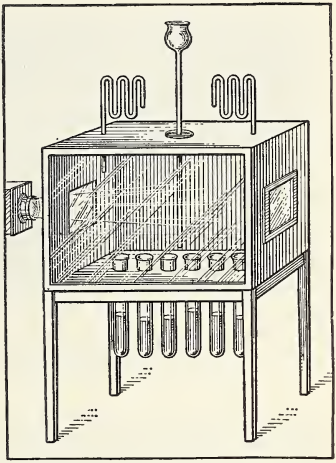


Fig. 357. Tyndall's apparatus. The box was entirely closed, and the inside was coated with glycerin to catch the dust particles as they settled. A light flashed through the windows indicated when all dust had settled. Air could enter the box only through the bent tubes, which caught the dust in their bends. The infusions, which were poured through the thistle tube into the test tubes, were boiled by dipping the ends of the test tubes into boiling oil. No life developed in any of the tubes. Later, however, when Tyndall removed the test tubes and exposed their contents to the outside air, all of them soon spoiled. How did this last step in the experiment serve as a control?

Self-test on Problem XXVIII–A. **1.** The theory that living things come alive out of inorganic materials is called the theory of *spontaneous generation.*

2. One difficulty which the early experimenters on spontaneous generation encountered was (1) in keeping dust out of the broth; (2) in killing the living things already in the materials from which the broth was made; (3) in the proper use of the microscope; (4) in learning the life histories of insects; (5) in properly closing their flasks with cotton.

[1] To the Teacher. Some leading biologists now believe that the so-called filterable viruses are the simplest forms of life, and that these may even represent the beginnings of life. This topic is too technical to be developed fully in an elementary discussion.

U. S. Bureau of Biological Survey

FIG. 358. Mother bear and cubs, Yellowstone Lake, Wyoming. By what processes will the cubs finally attain the size of the mother?

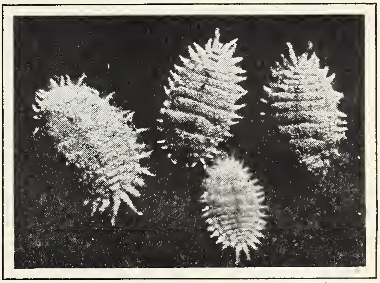
3. Select from the following list the names of the scientists who were prominent in disproving the theory of spontaneous generation: (1) Aristotle; (2) Tyndall; (3) Burbank; (4) Edison; (5) Pasteur; (6) Ross; (7) Browne; (8) Buffon; (9) Van Helmont; (10) Redi; (11) Lister; (12) Needham.

Problem XXVIII-B · What are the Ways in which Simple Plants and Animals Reproduce?

Growth and reproduction. It is a matter of common knowledge that living things are small when they begin their life. It is an interesting fact, however, that young animals of each kind are usually of about the same size (Fig. 358); also that fully grown animals of the same kind are of about the same size. For every adult organism there is a "most successful size." To be a successful animal, that is, to survive and reproduce, an animal must not vary too greatly from the average size of its kind.

The nonliving material which animals take in as food is changed by the protoplasm of their bodies into living protoplasm. New cells and new tissues are formed. It is by this process of growth that living things increase in size or add new parts to their bodies.

When growth has continued long enough for the organism to become mature, reproduction may occur. In the process of reproduction some part of the living body is separated and leaves the parent body on which or within which it was developed. It may then begin to develop into a new individual. There is no reproduction unless some portion of a living organism is able to leave its parent's body and to live independently.



Cornelia Clarke

FIG. 359. Mealy bugs (enlarged). Some scales and plant lice usually reproduce asexually. How does this characteristic make them harder to get rid of as plant pests?

Kinds of reproduction. There are several kinds of reproduction. These can conveniently be grouped as reproduction without sex and reproduction with sex. One type of reproduction without sex is illustrated by such plants as a strawberry, blackberry, or rose. When a branch of such a plant touches the ground, it may develop roots, a new stem, and leaves. Thus a new plant starts directly from the growing, or vegetative, part of the old plant. This process is called vegetative reproduction. Another type of reproduction without sex is illustrated by bread mold. When in such a plant a certain cell divides to form many small cells, called spores, each of these spores may grow and become a new mold plant. Such reproduction brought about by cells formed wholly by cell division is called asexual-spore reproduction. Asexual reproduction is reproduction without the union of reproductive cells from separate sexes. There are other methods of reproduction without sex which will be described later. When two separately formed cells unite to form a cell which may then grow into a new plant or animal, the process is called sexual reproduction.

Asexual reproduction is the older, more primitive method of reproduction. This method is more common in the lower, more primitive organisms. However, occasional examples of this

method are found as high in the scale of animal life as the insects, (Fig. 359), though those insects which reproduce without sex also reproduce sexually. The larva of a gall gnat, for example, and the pupa of a midge can lay eggs which will hatch and finally develop into adults. These insects also reproduce sexually in the adult stage. Many of the plants and many of the lower animals have more than one method of reproduction without sex. Sexual reproduction is the only method found among the chordates, but it is also found in plants and animals very low in life. The remainder of this chapter will discuss chiefly four methods of reproduction without sex in plants and animals, namely, reproduction by fission, by budding, by asexual-spore formation, and by vegetative reproduction.

Self-test on Problem XXVIII–B. **1.** When a portion of an organism separates from the parent's body and begins life for itself, *reproduction* is said to have taken place.

2. The chordates reproduce *vegetatively.*

3. More of the simpler animals and plants reproduce by *sexual* than by *asexual* means.

4. *No* animals reproduce asexually.

5. Asexual reproduction begins with *one cell.*

6. Sexual reproduction is possible only when *many* cells unite.

Problem XXVIII–C · How do Plants and Animals Reproduce by Fission and by Budding?

***Reproduction of plants by fission.** The simplest method of reproduction is by the process called fission. In this process the organism divides into two parts (Fig. 360). The simplest one-celled plants, such as the bacteria, reproduce by this method only. When a bacterium has reached its full size, if conditions are favorable it may divide into two bacteria. The cell divides at the middle into two cells with part of the original protoplasm in each new cell. If conditions are favorable each new cell rapidly grows to the size of the parent cell. Soon it is ready to divide again.

Each new bacterium carries on its life activities independently of the other half of its former self. In a sense these two new cells

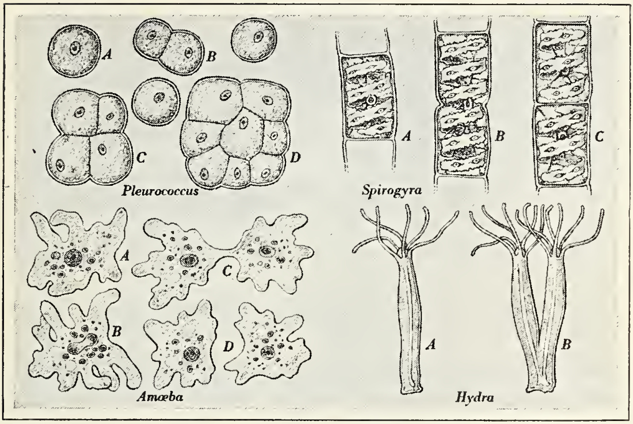


FIG. 360. Reproduction by fission. Can you explain all four parts of this figure? Can you explain why bacteria are often found attached together in chains? What do you understand to be meant by the conditions which would be favorable to fission?

are still parts of the single parent cell. Succeeding cells are likewise partly old and partly new, since part of the parent's body becomes directly a part of the body of the offspring. Plants and animals which reproduce by fission may starve to death or be killed by high temperatures or other severe conditions, but they never die of old age. They continue to reproduce indefinitely while their living conditions remain favorable.

In some plants the cells formed by fission do not entirely separate (see *Pleurococcus*, Fig. 80, p. 131). Thus *Spirogyra* consists of long threads, or strands which are made up sometimes of hundreds of cells joined end to end. The strands grow in length by the independent reproduction by fission of the separate cells.

Reproduction of animals by fission. The Protozoa reproduce by simple fission. This method of reproduction, moreover, is found in animals as high in the scale of life as *Hydra*, and even in some of the flatworms. Most of these animals which reproduce by fission reproduce also by other means, asexual or sexual, or, in many instances, by both.

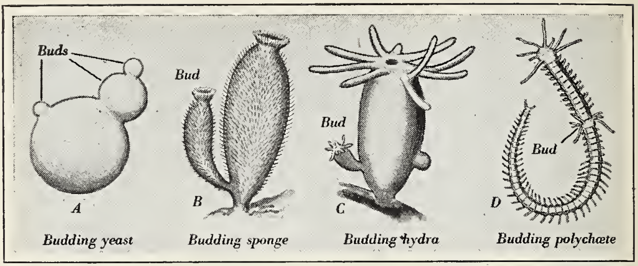


Fig. 361. Reproduction by budding in simple plants and animals. Compare the process of reproduction by budding with that by fission

***Reproduction by budding.** A somewhat different method of asexual reproduction, called budding, occurs with yeast plants and with some simple animals. Instead of having the protoplasm of a whole yeast cell divide into halves, a bud is formed on one side of a yeast cell (Fig. 361, *A*). This bud, at first very small, enlarges rapidly. The nucleus of the old cell divides, and one of the divisions passes into the developing bud. After a while a wall forms so as to separate the bud from its parent cell. It may soon become free and proceed to grow until it reaches adult size. Sometimes a bud will itself develop a second or even a third bud before the first one is free from its parent cell. When this occurs a small chain of yeast cells may be found, though each cell is really a new plant because when set free it can live alone.

Among animals, many of the Protozoa, the sponges (Fig. 361, *B*), and such cœlenterates as *Hydra* (Fig. 361, *C*) use budding as one of their several methods of reproduction. Occasionally examples of budding are found among animals as high in the scale of life as the annelids (Fig. 361, *D*).

Budding differs from simple fission in the relative size of the offspring produced. With fission the two individuals formed are of the same size and are similar in every way. In budding the new individuals are always smaller than the parent. Moreover, in fission the parent cell disappears. All its parts appear in the two "daughter" cells. In budding, however, the parent cell continues to live, along with its offspring.

Self-test on Problem XXVIII–C. 1. In fission *one* of the resulting organisms is older than the other.

2. The method of reproduction by which a simple animal divides into two complete animals is called *budding*.

3. In *fission* the new cell is smaller than the parent cell.

4. In *budding* the newly formed cells are of equal size.

5. *No* animals except the simplest ones reproduce by budding and fission.

Problem XXVIII–D · How do Plants and Animals Reproduce by Means of Spores?

Reproduction of plants by asexual spores. The formation of spores by bacteria, Protozoa, and other simple organisms has already been mentioned. Such spore formation occurs when there are unfavorable living conditions such as great cold, heat, or dryness. The protoplasm contracts in the middle of the cell, and the cell wall becomes thicker. Sometimes an inner heavy wall is formed close to the condensed protoplasm. In this condition the cell may remain dormant, or inactive, for months or even years.

When it is again placed where the living conditions are favorable, the protoplasm becomes active. It enlarges, breaks the hard wall, and proceeds to grow just as if nothing had ever occurred to interrupt its normal life.

This method of forming spores is an important adaptation for survival. It is not, however, a true method of reproduction because no part of the organism splits off and carries on life independently. No new individuals are formed directly. There are, however, true methods of reproduction of new individuals by spores among practically all the algæ and fungi — such as bacteria, yeasts, molds, mushrooms, rusts, blights, smuts — and also among many of the Protozoa.

*Reproduction of simple plants by asexual-spore formation is well illustrated by yeast. During this process the wall of the plant becomes thicker. The protoplasm within divides into two masses, then into four, and finally into eight. If living conditions are unfavorable, it may pass through a period of quiet with the eight cells, or spores, held by the old cell wall. Finally the old cell wall

dissolves and sets each of the spore cells free. Each one grows as a new yeast plant. Each reproduces again by the more common method of budding, although some of its descendants may later form spores.

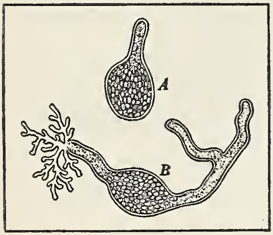


Fig. 362. The *Vaucheria* zoospore, *A*, was formed in the tip of a branch of a mature plant. This one has now started to grow by forming the beginning of a new plant. A later stage, *B*, shows two branches of a young plant, also the rootlike parts at the other end. What later stages develop as the plants grow?

A somewhat different type of asexual reproduction by spores is illustrated by *Vaucheria*.[1] This plant is one of the green algæ and is sometimes called "green felt." Its plants often grow in great numbers, forming mats of soft green growth upon damp soil along the shores of our ponds and streams and on the soil of pots and upon the benches and stands in greenhouses. A wall is sometimes formed across a branch of *Vaucheria* near the end, cutting off a small part of the tip, in which several nuclei are inclosed. After a short time the protoplasm within the tip develops into one large mass, or spore (Fig. 362, *A*), which pushes its way through a break in the wall and escapes. Small cilia enable this spore to swim about for a time. When this body was first discovered, it was thought to be an animal spore (zoospore), because it was then thought that only animals can swim. This spore finally comes to rest and grows into a new *Vaucheria* plant (Fig. 362, *B*). Other plants reproduce asexually by swimming spores in ways more or less like that of *Vaucheria*.

Reproduction of animals by asexual spores. Of the Protozoa which reproduce by spores, *Amœba* is most familiar. One of these animals contracts into a ball and surrounds itself with a three-layered wall (sometimes called a cyst). The nucleus then divides, first into two parts, then into four, and so on until as many as five hundred to six hundred daughter nuclei may be thus pro-

[1] This plant was named in honor of the Swiss scientist Vaucher, who first described it. His name was pronounced vo shere′, but the name of the plant is pronounced vo kee′ri a.

duced. Each small daughter nucleus then becomes surrounded by a wall and thus becomes a spore. No free protoplasm is left to build up the old cell, hence its wall finally breaks, releasing the hundreds of spores. In about three weeks under favorable life conditions the new individuals of *Amœba* have grown and developed to look like their parent. If conditions are favorable, these mature amœbas will reproduce by fission, which is the commoner method by which this animal reproduces. Reproduction of *Amœba* by the formation of asexual spores is relatively rare. Some of the parasitic Protozoa — for example, that which causes malaria — may reproduce by spore formation.

Self-test on Problem XXVIII–D. 1. New individuals develop from *all* spores.

2. When spores *germinate*, one cell develops finally into *two* new cells.

3. A plant which has swimming spores is the __(?)__.

4. In asexual reproduction by spores the spores divide always into an *odd* number of new cells.

5. In asexual reproduction by spores *one* of the resulting cells is older than any of the others.

Problem XXVIII–E · How do Plants and Animals Reproduce Vegetatively?

Vegetative reproduction of plants by regeneration. Some very simple plants, as well as many of the higher ones, are able to reproduce asexually by growing a complete plant from a part of the vegetative parent plant. For example, if a strand of *Spirogyra* breaks at any point, each part is likely to continue to grow independently as a new plant. *Vaucheria* furnishes another example. As it grows, it forms branches. If the older part dies, the branches may continue to grow as independent plants. Also, as has been stated earlier in this chapter, many kinds of higher plants will grow new roots at points where a branch comes in contact with the soil. After these roots have become well established, the branch which connects them with the old plant dies, and an entirely new plant is formed. After a while this new plant may produce others in the same way. By this means such plants reproduce

and spread in the neighborhood of the parent plants. In such vegetative reproduction the old individual merely has one of its growing parts "strike out for itself" as a new individual. The parts of higher plants which thus run along are called runners, or stolons. Such reproduction, in which a small part of the organism grows and reproduces all the other parts necessary to make it a complete organism, is called regeneration.

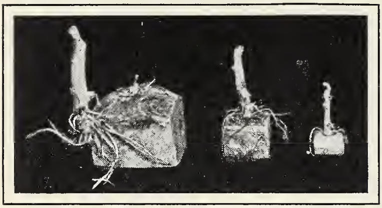


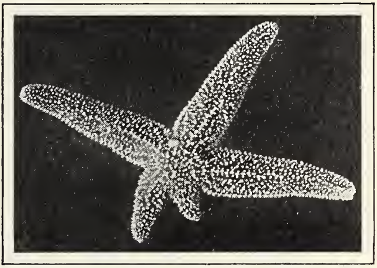
Fig. 363. Potato plants grown under identical conditions. How do you account for the difference in size of the young plants? Exercise on Scientific Method (Using Controls): How is each a control for the other two?

*** Vegetative reproduction by cuttings of plants.** If willow twigs are placed with the ends in water for a few weeks, roots usually develop at joints in the twigs. Such rooted twigs will grow if planted out of doors in good soil and if kept well watered. This is merely an artificial way of causing the willows to reproduce themselves by regeneration. Many other woody plants may be caused to reproduce in this way. This method of reproduction has long been used by men in regenerating, or propagating, plants which they found useful.

Such house and garden plants as geraniums, coleus, salvia, grapes, and roses may be reproduced by cuttings. If they are placed in sand and kept with favorable temperature, light, and moisture, they soon produce roots and may then be planted wherever it is desired to have them grow. An especially desirable individual plant may be multiplied by this means into a very large number of new plants.

A special kind of cutting is used in growing the common white potato. The tuber has a few buds commonly called eyes. It is so cut that each piece or cutting has a few buds. When these cuttings are planted, roots, stems, and leaves are regenerated from the buds (Fig. 363). Finally, short new underground stems (rhizomes) grow, and the new potatoes are formed at the ends of these short stems.

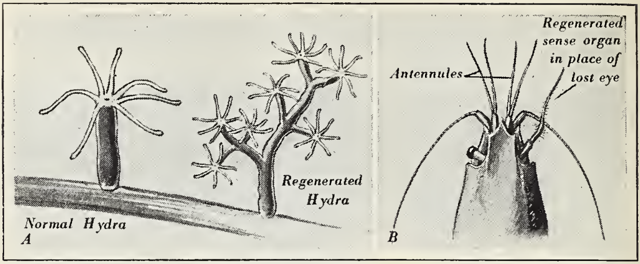
Vegetative reproduction of animals from cuttings. While experimenting with *Hydra* about two centuries ago, the French scientist Trembley made the astonishing discovery that if the animal were cut into two, three, or even four pieces each part would develop into a complete new animal. These experiments furnished the first knowledge of regeneration of animals from pieces, similar to regeneration of plants from cuttings. For example, the ability of sponges to regenerate from cuttings has now been put to commercial use. Sponge cuttings about an inch square are placed on small metal disks placed upon stakes or wire fences that are weighted down in shallow water. When the new animals have developed to the desired size, they can be more easily "harvested" than when they grow naturally. Flatworms and starfish (Fig. 364), like these simpler animals, will grow complete new animals from relatively small portions. The earthworm will usually grow a complete new animal from either of the cut ends. Some of the annelid relatives of the earthworm, however, will grow a tail behind a severed head end, but cannot grow a head on the tail part of the cut animal.



J. G. Pratt

FIG. 364. Regeneration of the starfish. Exercise on Scientific Method (Making Hypotheses and Inventing Experiments): At one time oyster-growers tried to rid oyster beds of starfish by cutting the starfish in two. A man would arm himself with a pole to the end of which a knife was attached. When he came upon a starfish, he hacked it in two with the knife. But instead of exterminating the starfish by this method, the growers soon found these animals more numerous than before. How do you account for this fact? Can you propose a method which might prove more effective in getting rid of starfish?

While experimenting with *Hydra* Trembley found that if he split the head and then separated the parts somewhat, each portion would regenerate the rest, so that a two-headed animal resulted (Fig. 365, *A*). Many animals are able to regenerate lost members. Only fairly primitive animals, however, are able to reproduce by



After Hegner

FIG. 365. Can you explain how this seven-headed hydra in *A* might have been produced? The antenna-like organ of the crayfish, in *B*, illustrates the fact that a regenerated member is not always like the member it replaces

regeneration. Thus an arthropod — for example, a spider or one of the crustaceans (Fig. 365, *B*) — will die if a vital organ or section of its body is removed, but it can regenerate a new leg.

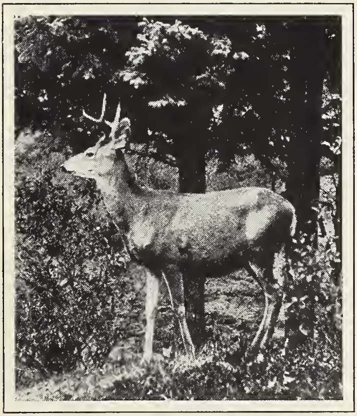


FIG. 366. A deer in Banff National Park, Alberta, Canada. The deer and its close relatives, the moose and the elk, lose their horns and regenerate new ones every year. Can you name other structures which man, other mammals, or birds can regenerate if lost?

The vertebrates have limited powers of regeneration. Some Amphibia can grow new limbs and tails. Few of the reptiles are able to regenerate missing members, though some lizards — for example, the swift and the glass snake — can regenerate new tails. These tails, however, are not like the original tails, since they contain no vertebræ. Regeneration in animals of the two highest phyla, the birds and the mammals, consists only in the repair of broken bones, the healing of wounds, and also the replacement of a few special structures

such as feathers and hair (Fig. 366). The young animals of every kind have considerably greater powers of regenerating lost or injured structures than have the old individuals of the same species.

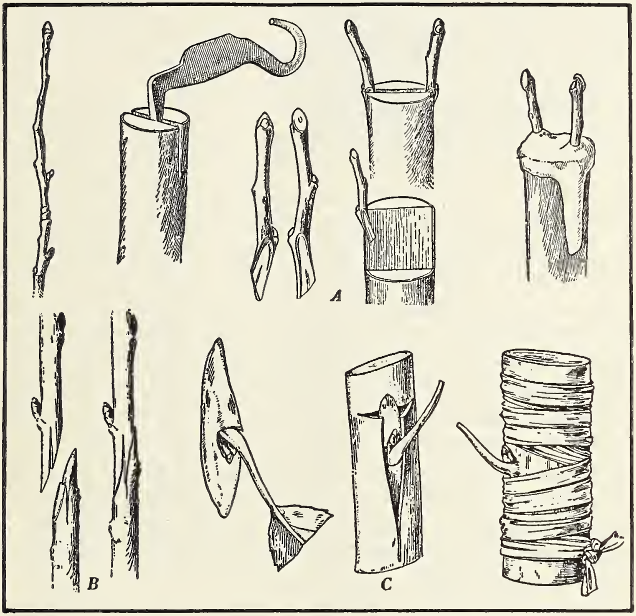


FIG. 367. *A*, cleft grafting; *B*, whip grafting; *C*, budding. Can you explain?

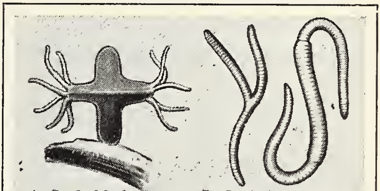
***Vegetative reproduction of plants by grafting.** It has long been the practice to grow apples, peaches, oranges, grapefruit, English walnuts, roses, and many other fruit and flowering plants from cuttings taken from the plants known to produce the best fruit or the best flowers. Instead of causing these cuttings to produce roots and then planting the rooted cuttings separately, such cuttings are made to grow upon the branches or stems of other plants (Fig. 367). First a branch or stem containing a bud is cut from the desired plant. This cutting must then be so fastened into the cut surface of the branch or stem on which it is to be grown

that the growing cells of cutting, or scion, come in contact with those of the old stem. The cambium tissues of the new branch and of the old stem grow together. By having the same kinds of cells united the soil water may pass upward through the xylem to the top of the cutting. Likewise the food that is later manufactured by the leaves of the cutting may pass downward through the phloëm into the roots of the plant.

*Since the grafted portion secures only water from the stem to which it is grafted, its character does not change. Grafting is thus a means of making widely available and permanent the desirable kinds of flowers, fruits, nuts, or foliage. For example, the navel-orange trees have all been produced directly or indirectly from one parent tree. Often the cutting of the desired plant may be grafted upon the root of some especially vigorous but otherwise less desirable plant which may not be even closely related to the one from which the cutting is taken. Thus apple twigs or buds may be grafted upon the stems of wild hawthorn trees, and the sturdy wild tree is thus caused to produce good apples. The most beautiful and highly specialized roses may be grown upon strong but ordinary rosebushes. English walnuts are commonly produced by grafting cuttings from English-walnut trees upon the stems of black-walnut trees. The Koster spruce, an especially beautiful blue spruce, is reproduced by grafting small branches of it upon the roots and stems of other spruces which do not possess the desired blue foliage.

New methods of plant-grafting. Those who have grown such plants as geraniums, coleus, and salvia from cuttings know that constant care must be given to keeping an even supply of temperature, moisture, and light. Too much or too little light or moisture or too high or too low temperature kills the cuttings. Too much moisture and heat may favor growth of destructive diseases. It has been found recently that too much of certain gases in the air will also prevent growth. Recent experiments have shown that woody plants, as well as the house and garden plants more commonly used in grafting, may be made to take root and grow without being grafted upon other plants. This is done by keeping the cuttings under special conditions of moisture, light, heat, soil composition, and gas composition of the air.

Reproduction of animals by grafting. Experiments have shown that grafts similar to those made with plants can be successfully made with some of the lower animals. Strange, complete new creatures have thus been produced with the hydras, the flatworms, and even animals as complex as angleworms (Fig. 368). Certain kinds of grafts, moreover, can be successfully made upon one of the higher animals, provided such grafts require the animal only to regenerate, or heal, a wound or an injured bone. Knowledge of this fact is often used in modern surgery. For example, skin taken from the thighs and grafted upon burned tissues has frequently saved the lives of persons who have suffered serious burns. Recently, also, when a man had lost a finger, a surgeon made him a fairly useful new finger. This was done by grafting upon the severed bone a piece of bone taken from the patient's leg bone and then molding round this bone a piece of flesh taken from the patient's abdomen. Not only did the bone from the shin grow to the finger stump and the flesh from the abdomen grow round the transplanted shin bone, but the wounds made in the shin and the abdomen also regenerated, or healed. Another surgeon successfully grafted into one patient's arm a four-inch section of nerve which he took from another patient's leg which had been cut off. Doubtless still further uses of grafting will develop as medical science, particularly surgery, advances.



A. Grafted hydra *B. Grafted earthworm*

FIG. 368. This double-headed hydra resulted from grafting part of one hydra on another. Can you suggest how these odd-looking earthworms were produced? (After Hegner)

Self-test on Problem XXVIII–E. 1. Reproduction of plants from cuttings is an example of *generation.*

2. The "eyes" of a white potato are *buds* from which new potatoes grow.

3. Regeneration of complete animals from a part is possible with animals as high in the scale of life as *mollusks.*

4. Regeneration of new legs of an animal is possible with animals as high in the scale of life as the *arthropods.*

5. Regeneration of broken bones and wounds is possible with animals as high in the scale of life as the *fishes.*

6. In grafting, plants may be grown upon the *roots* of other kinds of plants.

7. Successful grafting has been practiced with animals as high in the scale of life as *birds.*

Self-test on Mastery of Facts. Summarize all the ways in which the four methods of reproduction described in this chapter are alike and are different.

Self-test on Biological Principles. **1.** What evidence can you state from Problem XXVIII–A which tends to support these principles?

Man's ideas of what is true change as more facts are learned.
Scientific knowledge grows slowly.
Scientific truth is built up by means of many small additions.
Scientific progress is not always steadily forward.

2. Regeneration is of great value to organisms in survival. Can you explain this principle?

3. What evidence can you cite from this chapter to support the principle that "Life springs only from life"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** In accordance with the statement in this chapter, name in the order of increasing complexity the classes of chordates which reproduce sexually only. Name in order of increasing complexity all the animal phyla representatives of which may reproduce both asexually and sexually.

2. When conditions are most favorable, bacteria may divide as often as once every fifteen minutes. It has been estimated that if conditions remained favorable there would be 281,474,976,710,656 bacteria resulting from a single bacterium in twenty-four hours. These bacteria would make a solid sphere about four inches in diameter. In a relatively short time, if all conditions remained favorable, there would be a ball of bacteria the size of the earth. List as many reasons as you can which prevent the bacteria from producing at their maximum rate.

3. Small and dry spores of bacteria may be carried great distances by currents of air. Mold spores have been found as high as eleven miles in the air. How do these facts explain the observation that organisms are widely distributed?

4. Reproduction by spore formation, as in the yeast plant, is closely related to reproduction by fission. Compare these two methods of asexual reproduction for ways in which they are similar and for ways in which they are different.

5. Compare the process of spore formation of yeast with that of *Vaucheria.*

6. Contrast the process of budding with that of spore formation.

Project 22. To use regeneration as a means of growing new plants. Secure cuttings from various house plants such as those mentioned, or cactus plants, or others. Place the ends in moist soil and keep the soil moist for all the cuttings except those of the cactus. Put these in sandy soil and dampen the soil only about once a week. Vary the conditions of moisture and the kinds of soil with different cuttings from the same kinds of plants. Keep a record of the plants with which you succeed and those with which you fail to secure healthy new plants.

Special Reports. 1. What did Leeuwenhoek and others besides those named in this discussion contribute to the overthrow of the theory of spontaneous generation? (This topic is usually listed in the encyclopedias under the name *abiogenesis.*) How was the theory modified after the invention of the microscope? What were the various steps in Lister's experiments to determine how infections could be prevented in surgical operations?

2. Find in an encyclopedia or in an advanced textbook of zoology the method of asexual reproduction called gemmulation. How does this method differ from that of ordinary spore formation?

3. Look up *heteromorphosis* in an encyclopedia for other examples of regeneration in which the new part is not like the one it replaces.

4. Look up *regeneration* in an encyclopedia, for further examples.

Chapter XXIX · Reproduction with Sex

Questions this Chapter Answers

What is sexual reproduction?
Can there be sexual reproduction without special structures to produce the sex cells?
How do sexual and asexual spores differ, and how are they alike?
Does the same plant or animal ever produce more than one kind of sex cells?
What are the stages in development of a seed?
What are the stages in development of the embryo of one of the higher animals?
Why are the numbers of sperms produced by plants and animals so very large as compared with the numbers of eggs?
Why are few young produced among the higher animals as compared with the numbers produced by the lower animals?

Problem XXIX–A · How is Sexual Reproduction Effected in the Simplest Plants and Animals?

Types of sexual reproduction. The preceding chapter has explained that the simplest plants and animals have no sex. Such organisms therefore usually reproduce by fission, by asexual-spore formation, by budding, by regeneration, or by some variation of one or more of these methods. In using these methods a single organism is capable of reproducing itself without the direct aid of another organism of the same kind. Most plants and practically all animals possess means of sexual reproduction by which a new individual is formed by the union of cells. The cells which unite are usually from different individuals, though in case of some plants and animals they may come from the same individual. Many of the plants and animals which reproduce by union of cells may also reproduce by means of the simpler methods already described (Fig. 369).

The simplest type of sexual reproduction is illustrated by some of the algæ and by such simple animals as *Paramecium* and certain other Protozoa. In these cases reproduction is accomplished without special sex organs. A somewhat higher type of sexual repro-

duction is accomplished by some of the algæ and fungi, the ferns, the sponges, *Hydra*, the earthworm, and the snails. These have

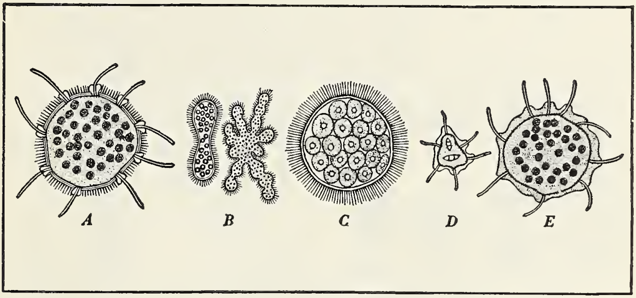


Fig. 369. This protozoan when mature looks like *A*. It reproduces both by simple fission and by budding (*B*), and also by spore formation (*C*). When the cell wall breaks, each new spore looks like *D* and develops into *E*. It reproduces again by fission and by budding, and finally reproduces by a sexual method not yet fully understood. Each animal formed by this last process develops into an animal like *A*. How many methods of reproduction does this animal (*Trichospaerium sieboldii*) have?

special sex organs, but both the male and the female structures are usually on the same plant or animal. In some of the mosses and ferns and in many higher plants each individual is either a male or a female. Of the more complex animals also, such as starfish, crayfish, and all the chordates, the individuals are always of one sex. This chapter will describe examples of these types of sexual reproduction.

Sexual reproduction without sex organs: conjugation. Although *Spirogyra* has no special sex organs, it nevertheless forms new plants by sexual reproduction abundantly as well as by the asexual means already described. The cells of two mature plants that are near one another produce tubelike growths from their walls, and these tubes finally join so as to form one continuous tube between the two paired cells (Fig. 370). While the connecting tubes are being formed, the chlorophyll bands and the cytoplasm in the paired cells become much reduced in size and the chlorophyll bands become indistinct. When the connecting tubes are completed, the protoplasm from one of the paired cells passes through

the tube into the other cell. The protoplasm from both cells then unites thus: the nuclei of the two cells unite, forming one nucleus,

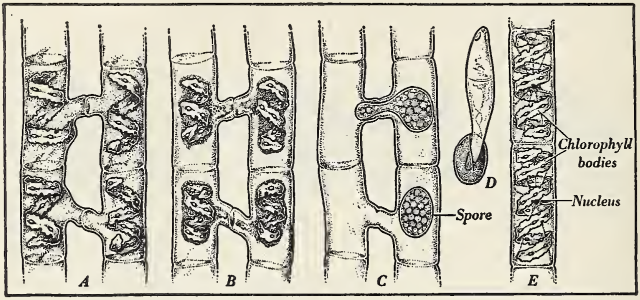


Fig. 370. Conjugation of *Spirogyra*. *A* to *C*, formation of spore by conjugation; *D*, a germinating spore; *E*, two cells of a growing plant. By study of the text can you interpret the stages shown? What methods of reproduction has *Spirogyra*?

and the cytoplasm from both cells unites into one condensed mass of cytoplasm, occupying but a small part of the old cell space. The result of this union is a spore. The old cell walls surrounding each spore decay and finally break, thus releasing the spore.

As the spore is being formed, it develops a thick wall about itself. This heavy-walled spore when released may sink to the bottom of the pond. It may remain inactive, or dormant, for a long time. Since it is protected by its thick walls, it may remain alive even though a long period of drought or extremely cold weather may kill all the vegetative spirogyra plants. When favorable growing conditions return, each spore cell may start to grow as a new spirogyra plant. The one cell with which it begins its growth divides into two cells, and these in turn grow and divide until a many-celled plant has been formed which looks like the parents. If two spirogyra plants have fifty or more paired cells, as they often do, the spores could produce fifty or more new plants. It should be remembered, however, that the spores are not only a means of reproduction but also a means of enduring unfavorable conditions.

Comparison of sexual and asexual spores. Since the spirogyra spore is formed by union of cells, it is called a sex spore (or zy-

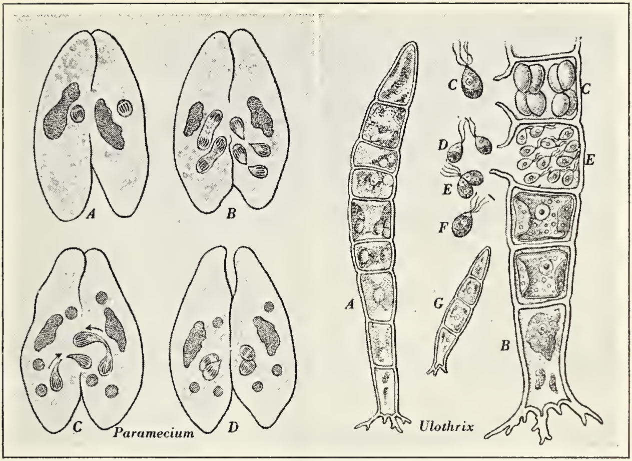


Fig. 371. Judging from these figures, in what respects is conjugation of *Paramecium* different from that of *Ulothrix*, a green alga? Special Report: Look up conjugation of *Paramecium* and of *Ulothrix* in advanced zoology and botany textbooks

gospore). The two cells that unite to form a sex spore are reproductive cells. Such sex cells which may unite to form a sex spore are called gametes. They are reproductive cells but cannot reproduce alone. That is, *gametes* are those cells that are specialized for the purpose of joining together to form spores. In *Spirogyra* the gametes are alike in appearance, though in most other plants and animals they are of two different kinds. In biology it is common to call the process of uniting similar gametes *conjugation*, which means "yoking together."

The asexual spores of yeast and *Amœba*, which were discussed in the preceding chapter, are formed from a single cell. They are the result of cell division. Each of the sexual spores of *Spirogyra*, however, is formed from two cells, called gametes. Sexual spores are therefore formed, not by cell division, but by cell union (Fig. 371). A single gamete cannot produce a new individual of itself, as can the asexual spore. Reproduction by gametes, therefore, is only possible through conjugation.

Self-test on Problem XXIX–A. **1.** Sexual reproduction is *never* accomplished by one animal.

2. Both sexes are *seldom* found among the simplest animals and plants.

3. A gamete is *seldom* able to reproduce alone.

4. The gametes of the same plant are *always* alike.

5. *Asexual* spores are always formed by the union of two cells.

6. *Sexual* spores are formed by the division of one cell.

7. In conjugation the two gametes which unite are *different.*

Problem XXIX–B · How is Sexual Reproduction Effected in Plants and Animals which Have Sex Organs?

Sexual reproduction by organisms having both male and female organs. A simple type of sexual reproduction by a hermaphroditic organism, that is, one having both male and female sex organs, is illustrated by *Vaucheria.* There are slight differences in the sex organs in different species of *Vaucheria* plants. The sex organs of two species of *Vaucheria* are shown in Fig. 372. One kind of long, special branch is sometimes formed, in which many small reproductive cells are developed. These cells are the male gametes, or sperms. Each has a nucleus, a small amount of cytoplasm, and two long threads of cytoplasm called cilia. By means of these cilia the sperm can swim in any available water, even in a film of dew. Another globelike, special branch (Fig. 372) produces one large reproductive cell, which is the female gamete. or egg. One or more of the swimming sperms may enter the egg case, or

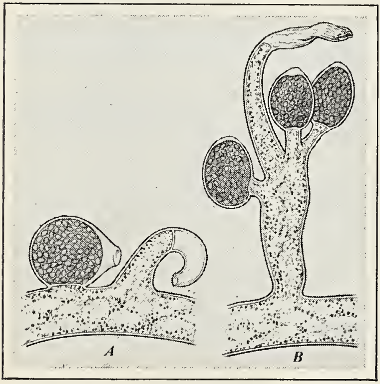


FIG. 372. Reproductive organs of two kinds of *Vaucheria.* Sex organs grow as branches from the plant. How do the sperms get from the male sex organs into the rounded female organs, each of which contains an egg?

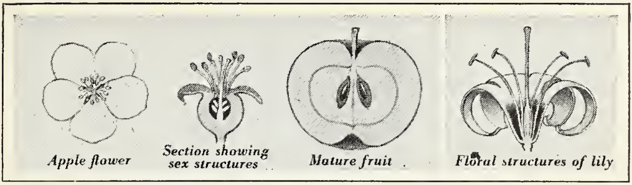


FIG. 373. Are these complete flowers? Are they perfect flowers? (See Glossary)

female sex organ. One of them may unite with the egg cell to produce a spore. This spore develops a heavy wall. After a resting period the spores may finally produce new *Vaucheria* plants.

Sexual reproduction of *Vaucheria* marks a stage of development more complex than that of *Spirogyra,* because reproduction of *Vaucheria* is brought about by the union of gametes which are very unlike. It is also more complex because there are special sex organs in which the gametes are produced. Furthermore, a very small and active sperm swims to and joins with a relatively large stationary egg. The process of uniting the sperm and the egg is called *fertilization.* Without this union neither egg nor sperm can produce a new organism. The process of sexual reproduction, in which a male gamete, or sperm, unites with a female gamete, or egg, and fertilizes it, is found in all but the simplest plants and animals.

Reproduction in higher plants. A flower is a special device for reproduction. It consists of many parts, each of which is in some way related to reproduction. No two kinds of plants have flowers exactly alike; hence any flower used for illustration will be like other flowers in its essential features only. The flower of an apple tree or the flower of any common plant of the field or greenhouse will provide good material for class use. Four sets of structures compose the apple flower: the sepals, the petals, the stamens, and the pistil (Fig. 373). The outer small and green leaflike sepals together make up the calyx. In the apple flower the sepals are joined except at their tips. They inclose and protect the other parts of the flower, especially during the bud stage. The brightly colored leaflike petals together make up the corolla. This structure further incloses and protects the inner reproductive parts

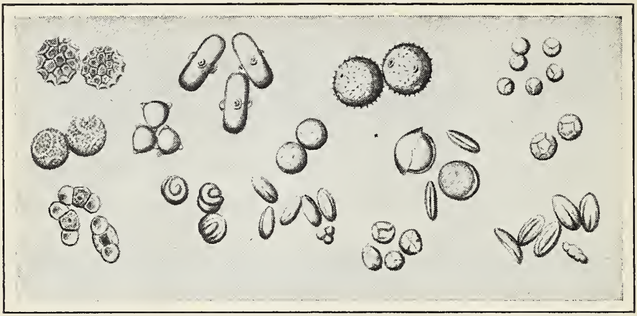


FIG. 374. Pollen grains. Project 23: To study pollen from as many different garden flowers and wild flowers as possible. Make sketches of the types you observe

of the flower. The color of the corolla and the odor of the flower may serve to attract insects, which carry pollen from flower to flower. Within the corolla are the stamens. At the center of the flower is the pistil, within which the seeds are formed.

How the seed is formed. The enlarged part near the base of the pistil is called the ovary, which contains the ovules. The ovule, or developing seed, was once wrongly supposed to be an egg; hence its name *ovule*, which means "egg" (Fig. 373). Inside the ovule, among the other cells, is one large cell which continues to enlarge until it occupies most of the interior of the ovule. Because this enlarged area will later contain the embryo plant, it is called the embryo sac. While this cell is enlarging, its nucleus undergoes a number of changes. These changes finally result in forming several cells, of which the most important are the egg cell, or female gamete, near the tip of the embryo sac, and another large cell near the middle of the embryo sac.

Inside the tip of the stamen the small spores, or pollen grains, are formed (Fig. 374). When ripe they escape and are carried by currents of air or by insects. In some kinds of flowers the pollen is carried by birds and other animals that visit the flowers in search of a sweet secretion called nectar that is produced in many flowers. If the pollen grains come in contact with the stigma of a mature pistil (Fig. 375), they stick to it. Each pollen grain be-

gins to grow and soon produces a tube which extends downward through the pistil toward the ovules. While this pollen tube is developing, its nucleus undergoes several divisions; and finally two male gametes are formed within it. Upon reaching an ovule the pollen tube grows into the end of the embryo sac and releases the male cells. One of the male gametes unites with the egg, that is, fertilizes it. The other, in many cases at least, unites with the large cell in the middle of the embryo sac. The cell formed by this second union does not grow into a new plant as does the fertilized egg, but develops into a large amount of nourishing tissue called the endosperm, which serves as food for the development of the young plant (Fig. 376).

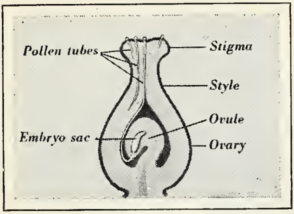


FIG. 375. Under what conditions will pollen grains germinate?

*The fertilized egg begins its growth at once. The developing new plant is called the embryo. As the embryo develops, it grows toward the center of the sac and thus is surrounded by the developing endosperm, which it digests and absorbs. Soon it has formed a small root, one or two leaves, and the beginning of a stem. It then stops growing. The wall of the ovule becomes dry and hard, inclosing the embryo and any remaining endosperm. This whole structure is called a seed. Many such seeds may be formed within the ovary of one flower. The young plant remains in a dormant stage during all the time between the ripening of the seed and its germination.[1]

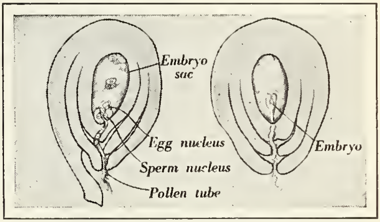


FIG. 376. Fertilization of an egg (left), and developing embryo (right). What processes have preceded the stages shown here?

[1] *Germination* (jur mi na′shun): the name given the process by which a young plant bursts through its seed coat and continues its development.

***Seeds, fruits, and seed distribution.** In many plants as soon as the seeds are formed the ovary, in which they grew, opens and

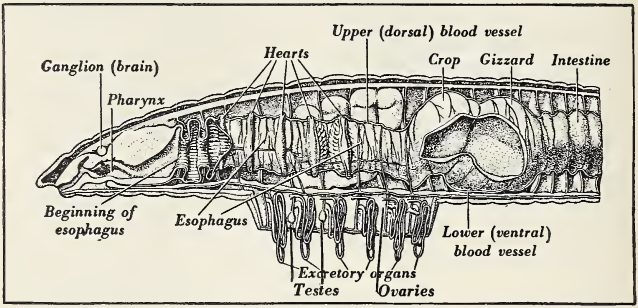


FIG. 377. The earthworm, a hermaphrodite,[1] has both male and female sex organs. What other hermaphroditic animals can you name?

releases them. In many others the ovary wall or even other parts of the flower change into structures which remain around the seeds, forming a fruit. The fruit of any plant consists both of the seeds and of anything else which ripens with them. In the apple and pear, for example, the seed, the ovary wall, and part of the sepals develop into the fruit. In the peach and apricot the wall of the ovary divides. Its inner part forms the shell, or hard wall around the seed, while the outer part develops into the pulp. The pineapple fruit is formed by the ripening of all the flowers as well as the flower stem and the branch of the plant which produced the flowers.

The fruits serve as aids in securing distribution of seeds, since birds and other animals seeking the fruits as food carry them away and frequently drop them at some distance from the parent plants. Moreover, the seeds of such plants as the maple and the ash have wings by which the seed may float long distances through the air; the seeds of such plants as burdock and cocklebur have hooks which may catch in the fur of passing animals, with the result that the seeds may be more widely distributed.

Sexual reproduction in hermaphroditic[1] animals; the earthworm. In the common earthworm the ninth and tenth segments

[1] *Hermaphrodite* (her maf′ro dite): an animal or plant having both male and female sex organs.

contain certain organs called testes (singular, testis), which produce the male gametes, or sperms (Fig. 377). In the fourteenth segment are the female sex organs, or ovaries, which produce the female gametes, or eggs.

Two of the animals whose sperms are mature attach themselves together, and an exchange of some of the sperms takes place between the two animals; that is, each receives some sperms from the other. The swollen region (the clitellum), of each worm secretes material which forms a band, or cocoon. This cocoon is pushed forward slowly by the movements of the worm. As it passes over the openings of the sex organs the cocoon receives eggs from one of the worms and sperms that had been formed in the other. The eggs in each cocoon are fertilized by the time the cocoon passes over the head of the animal. The cocoon then contracts. Its surface becomes dry, hard, and brown. These cocoons, which look much like grains of wheat, are left embedded in rich earth, decaying matter, or under stones and logs, where the adult earthworms live. The fertilized eggs within the cocoon may remain dormant through a period of unfavorable weather.

The embryo earthworms are nourished by secretions left in the cocoon by the parent animal. In two or three weeks twenty or more young earthworms escape from the cocoon and begin to live independently. They soon reach maturity, thus completing the life cycle, and are themselves able to reproduce.

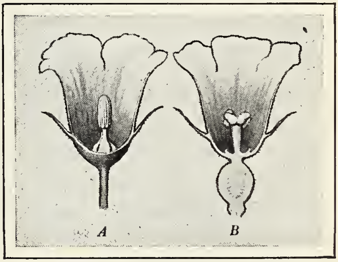


Fig. 378. Squash flowers: *A*, bearing only stamens; *B*, having only a pistil. Which flower will produce a squash? What part of the flower will produce the squash?

***Sexual reproduction of organisms having separate sexes.** As already indicated, animals and plants which have separate sexes are regarded as having reached a higher stage of development than those which have both sexes in the same individual. Many of the flowering plants have flowers that bear either male or female reproductive cells but not both, though both kinds of flowers are

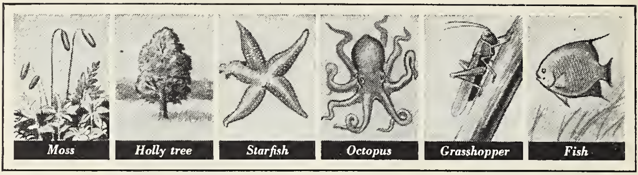


FIG. 379. Organisms with separate sexes. What is the lowest plant phylum and what is the lowest animal phylum represented in this picture?

sometimes on the same plant. Examples are squash, oak, and corn. Some kinds of plants are either male or female, since their flowers bear but one kind of sex cell (Fig. 378). Examples are willow and holly. Many have flowers that bear both male and female reproductive cells, but have these parts mature at different times. Only a few kinds of nonflowering plants have separate sexes. Of the animals, in general only the higher types have separate sexes. Thus some of the mollusks and all the arthropods and the chordates are either male or female (Fig. 379).

The method of reproduction with organisms having separate sexes is essentially the same as that of organisms having both sexes in the same individual. In all cases the sperms seek and fertilize the eggs. In animals the sperm always swims to the egg, either through the water or in a film of moisture on the lining of the canals in which the eggs are.

Self-test on Problem XXIX–B. **1.** The male gamete or *spore* is a living cell.

2. The *female* gamete seeks the *male* gamete.

3. *All* plants have separate sex organs.

4. The ovary of a flower contains the *male* gametes; the stamens produce the *female* gametes.

5. Pollen grains are *spores.*

6. The embryo remains dormant in the *spore.*

7. Animals with both male and female sex organs in the same individual are found as high in the scale of life as the *arthropods.*

8. In fertilization the two gametes which unite are *similar.*

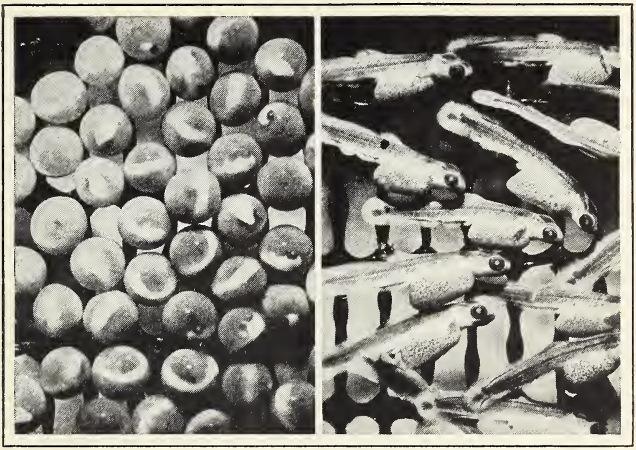


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FIG. 380. Developing embryos in trout eggs (left); young trout (right). Note that in certain eggs no embryos are developing. How do you account for this fact?

Problem XXIX–C · What are the Special Conditions Associated with Sexual Reproduction?

Higher organisms are less prolific than lower organisms. In the simpler organisms fertilization is largely a matter of chance. Thus, though only one pollen grain is necessary in the fertilizing of one egg within a plant ovule, plants produce pollen grains by millions. It may be that, from many millions, only one pollen grain or a few will happen to reach the mature pistil of a flower of the same kind at just the right time to fertilize its eggs. Therefore, if the plants did not produce pollen in enormous quantities, they would not survive. Likewise there is a large number of ovules, since many of them are certain not to be fertilized. Like the flowering plants, the water animals must be prolific; that is, they must produce vast quantities of sperms and eggs. Thus sponges, jellyfish, oysters, and even animals as high in the scale of life as some of the fish produce in a single season thousands or even millions of eggs (Fig. 380), and the males discharge so many sperms as some-

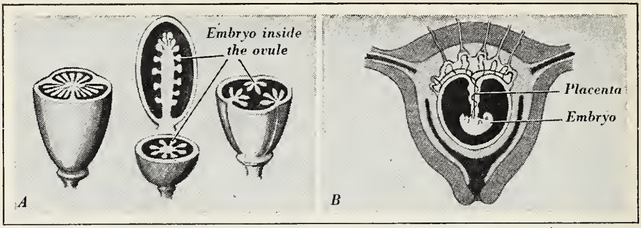

FIG. 381. What three different arrangements of the embryos and the placentas are shown in these plant ovaries (*A*)? Compare the development of the mammal (*B*) with that of the seed

times to make the water around the eggs cloudy. It may perhaps be difficult to understand why such great numbers are necessary when only one sperm is needed to fertilize an egg. A reason is that only a relatively small number of the sperms ever happen to reach the eggs and fertilize them. Moreover, many embryos must begin their development, because relatively few develop into adults.

In the higher animals, however, fertilization is far less a matter of chance. The males of all mammals, of birds, of reptiles, of some of the fishes, of practically all insects, and of some of the water arthropods such as the crayfish, deposit the sperms directly in the bodies of the females. Since by this method the fertilization of the eggs is practically assured, the numbers of sperms and of eggs of these animals are smaller than those of the simpler animals. In all cases, however, the numbers of sperms are always large when compared with the numbers of eggs. In addition to this provision for insuring fertilization of the egg, the higher animals also provide more or less care for their young. They therefore produce fewer young than the simpler animals, which leave to chance both the fertilization of their eggs and the fate of their offspring.

Some comparisons of developing organisms. The development of an embryo into a complete individual requires constant supplies of food energy. Until it has developed into a mature seed, the ovule of a seed plant remains attached to the walls of the ovary (by the placenta) (Fig. 381, *A*) and receives food from the parent plant. Food stored in the seed is used by the developing plant

FIG. 382. Young embryos look much alike. These figures represent three stages in the development of each of seven animals. Why would the three on the right remain much alike for a longer period of their development than would the others? (After Häckel)

until it can carry on the work of photosynthesis for itself. What is usually called the egg of a bird or other egg-laying animal is much more than the real egg. The real egg in a hen's "egg" is a small grayish mass attached to the yolk. Most of what is within the membrane and the shell of the "egg" is food which the embryo will use as it develops.

The embryo plant has already developed far enough to have its first leaves, stem, and root by the time the seed is ripe. It then goes into a resting stage until conditions become favorable for further development. The egg of a fish or a bird may accumulate food material, but the embryo develops but little before the egg is laid. It may then rest for a while before continuing its development. In the higher animals, however, the fertilized egg develops steadily from the first, with no resting stage such as that of the embryo plant in the ripe seed or of the fertilized egg which has been laid by a bird. Moreover, since the young mammal develops within the mother's body, it does not need stores of energy in the form of food reserves such as are within the seed and the bird's

egg. It is attached to the mother's body by the placenta (Fig. 381, *B*) in much the same way that the developing seed is attached to the ovary of the parent plant. Food passes by osmosis from the mother's blood to that of the embryo through this tissue. Waste materials pass by osmosis similarly from the blood of the embryo to that of the mother. The development of the embryo is so nearly the same for all the higher animals that it is difficult to distinguish the embryos of the various animals in the earlier stages of development (Fig. 382). The time required for the young animal's development before birth varies with different kinds of animals. The approximate period in dogs, foxes, and wolves is two months; hogs, four months; sheep and goats, five months; cattle, nine months; human beings, nine months; horses, eleven months; and elephants, two years.

Newton H. Hartman

Fig. 383. Kangaroo and young. What other pouched animals can you name?

In some animals, as the opossum, the kangaroo, and the bear, the young are born in an undeveloped condition. The mother opossum or kangaroo has a special pouch in which the young undergo further development (Fig. 383). These pouches are for protection and transportation of the young. The young secure nourishment from the milk, or mammary, glands, the nipples of which are inside the pouch. Bears are born during the mother's hibernation. At birth they are but a few inches in length. They remain attached to the mother's mammary glands and by the following spring have grown to several times their size at birth.

Protection of the embryo. The young moss or fern plant, as well as the young sponge or cœlenterate, undergoes the earlier stages of its development while embedded in the parent body. The embryo flowering plant begins its life within the protection of the ovule and ovary. Similarly the embryos of all egg-laying ani-

mals develop through certain stages while protected within the parent's body before the egg is laid. The embryos of such animals undergo still other stages of development within the protection of the eggshell or membrane during the period of incubation (Fig. 384). Likewise the embryos of all those animals which bear their young alive have the protection of the mother's body during the development before birth. Such protection of the embryo plants and animals is of great value in insuring the survival of the various species.

Stages of development in embryo animals. Higher plants and animals begin life in the same way, namely, as a fertilized egg. A small active sperm fertilizes a large stationary egg. The sperms of animals are in some cases — for example, one of the sea urchins — only one half-millionth as large as the egg. The sperms of plants and animals all resemble each other more or less, though each kind has distinguishing characteristics.

Before birth all the higher animals go through the same stages of development, and these stages occur always in the same order. The fertilized

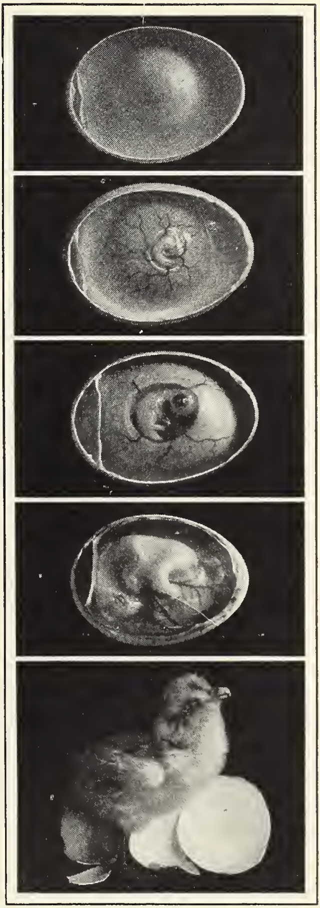

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FIG. 384. How the chick develops. The pictures show the stages of development on the second, fifth, tenth, fifteenth and twenty-first days of incubation. What structures can you find in each stage?

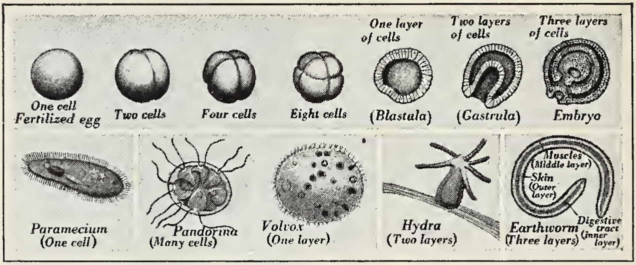


Fig. 385. In reaching the adult stage, the more complex animals pass through more stages of development than do the simpler ones. Explain how this diagram illustrates this fact

egg, which is a single cell, first divides into two cells, then into four, then into eight, etc. (Fig. 385). Finally a cavity develops in the middle of the cell mass, which now resembles a hollow ball the wall of which consists of a single layer of cells (the blastula stage of the embryo). On one side, where the cells are thicker than elsewhere, the cells begin to fold inward until the developing embryo is a cup-shaped structure (the gastrula stage) somewhat resembling a raspberry. The walls of this cup are composed of two layers of cells. Soon a third layer of cells begins to form between these two. Each layer develops into certain definite structures of the animal's body. From the outer one (ectoderm) develop the skin and the nervous system. From the inner layer (endoderm) develop the linings of all the organs of respiration and of digestion. The third, or middle, layer develops the blood, the blood vessels, the muscles, and the supporting tissues, such as the bones and cartilage, and later the organs of excretion and of reproduction.

Self-test on Problem XXIX–C. **1.** The lower plants and animals produce enormous numbers of sperms and eggs because (1) several sperms are necessary in fertilizing each egg; (2) there are so many chances against the sperms' finding the eggs; (3) fertilization is seldom a matter of chance; (4) fertilization of every egg is certain; (5) the organism does not need much of its energy for any other purpose than reproduction.

2. The embryo in the egg of a *chicken* continues its development from the time it is fertilized.

3. The egg of a mammal contains *large* stores of food for the developing embryo.

4. A pouched mammal native to the southern United States is the *kangaroo.*

5. The *sperm* seeks the *smaller* stationary egg.

6. In its development the *embryo* of any of the higher animals goes through stages which *resemble* the adult stages of simpler animals.

Self-test on Biological Principles. **1.** Can you state evidence from this chapter to explain this principle: "Nature is wasteful of life"?

2. If several pollen grains fall upon a mature pistil at the same time, all may begin to grow tubes toward the ovules, but the strongest will reach the ovules first. Similarly a million sperms may begin at the same time to swim toward the egg in one of the higher animals. One of the most vigorous will reach and fertilize the egg. How do these facts illustrate "survival of the fittest"? What advantage does the plant or animal gain from such "waste" of life?

3. How many illustrations of this principle can you give: "The number of young produced by an organism is in inverse proportion to the amount of parental care given to the young"?

4. Can you explain why in each of the following paired statements *a* is incorrect and *b* correct in accordance with this principle: "Those plants and animals are most likely to survive and reproduce which have structures and adaptations best fitted to the environment"?

a. Some plant seeds have hooks *in order that* these may catch in the fur of passing animals, thus carrying the seeds to new localities.

b. Some plant seeds may be carried to new localities *because* they have hooks which may catch in the fur of passing animals.

a. Certain animals have protective coloration *so that* they can more successfully escape their enemies or catch their prey.

b. Certain animals may more successfully escape their enemies or catch their prey *because* they have protective coloration.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** What do you think are some of the advantages to *Spirogyra* gained from its kind of spore formation?

2. Explain why, according to the definition given in this chapter, the following may be called fruits: tomato, cucumber, pea pod, and cocklebur.

3. What conditions can you name which might prevent the fertilization of fish eggs by sperms discharged into the water near the eggs?

Chapter XXX · Other Important Features of Reproduction

Questions this Chapter Answers

May the life cycle of some animals and plants have different stages that do not resemble one another?

What is meant by alternation of generations?

How does pollination differ from fertilization in plants?

Why is cross fertilization thought desirable?

Are the changes during the incubation of eggs of birds like the development of the mammal embryo?

What are advantages of parental care?

Problem XXX–A · How is Alternation of Generations Illustrated in the Life Histories of Moss and Fern?

The generations alternate.[1] In many kinds of plants and animals the life cycle consists of two distinct stages, both of which are needed in making the complete life cycle. Thus the free-swimming stage of a jellyfish reproduces the fixed, or quiet, stage of its life cycle. This second stage later reproduces the first stage. (See alternation of generations in the jellyfish, pp. 158–159.) One of the alternate phases of the life cycle produces sexual spores; the other reproduces asexually. In several of the lower animals, and in all but the lowest plants, there is this alternation of sexual and asexual generations. The moss and fern plants provide good illustrations of alternation of generations.

The life cycle of a moss. In the early stage of its growth moss consists of cells joined end to end (Fig. 386), with branches growing from the main chain of cells. This stage of moss lives by absorbing moisture and materials from the soil and by manufacturing food by photosynthesis. These branched and algalike threads of moss are called protonema.

[1] *Alternate* (al'ter nate): to follow one another, or to "take turns" one at a time.

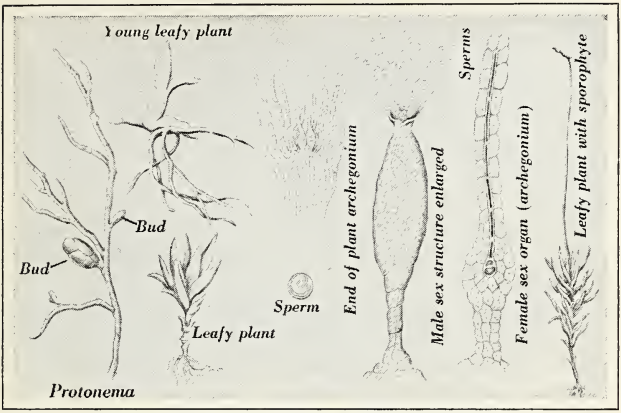


FIG. 386. Life cycle of moss. Explain this diagram

Sometimes a branch of the protonema becomes enlarged at its tip, and in this branch dividing walls develop so as to form a compact mass of cells called a bud. From some of the surface cells of the bud, rootlike processes (rhizoids) extend into the soil. From other surface cells, broad leaflike extensions develop. The central cells of the bud elongate as a stem, thus raising the leaves to the light. These leafy plants are to most people the only familiar stage in the life cycle of the moss.

At the tips of these leafy plants the sex cells of moss are produced in special sex organs. The male sex organ is shaped like an Indian club. Within it many sperms are developed. The female sex organ is shaped like a flask with the neck greatly extended. By means of their cilia the sperms swim in any moisture which may be on the leaves. By chance one or more of them enters the tip of the egg case and reaches the egg. One sperm unites with the egg. This fertilized egg of the moss is therefore formed within the female sex organ, or egg case, and is inclosed by the bases of the leaves of the leafy stage of the plant.

Instead of passing through a resting period the fertilized egg of moss starts growing at once. It divides into two cells, then these two into four, then eight, sixteen, and so on. The base, or foot,

of the embryo that is produced by the growth of the fertilized egg is tightly fastened into the tip of the stem of the leafy plant. The other end of this growing stem pushes upward an inch or more above the leafy plant. Its tip expands to form a structure which looks somewhat like a very small football. The stem and its capsule are green and can therefore carry on photosynthesis; but most of the nourishment is secured, through the foot, from the old leafy plant.

As the moss capsule matures, its inner cells divide and form many spores. Since these spores are formed entirely by division, they are asexual spores. When the mouth of the capsule opens, the spores may be distributed in a small cloud. They are so light that they may be carried long distances by currents of air. If they fall in favorable places, they absorb moisture and begin to grow and produce new moss protonema.

* **Summary of reproduction of moss.** In the moss life cycle the protonema, by means of vegetative buds, produces the leafy moss plant upon which sex organs and gametes are formed. This is the sex stage of the moss life cycle, producing gametes, which unite to form the fertilized egg. This stage of the life cycle is often called the gamete plant, or gametophyte.

* When the fertilized egg grows, it produces the other stage of the life cycle, the extended stem and capsule. Asexual spores develop in the capsule. The stage in the life cycle which produces asexual spores is often called the spore plant, or sporophyte. Neither gamete plant (gametophyte) nor spore plant (sporophyte) is a whole plant in itself, but each is a necessary stage in completing the whole moss life cycle. Each stage has been called a generation, although it is really but a part of the life cycle and is not what we mean when we speak of a human generation. The expression *alternation of generations* indicates the alternate stages in a life cycle, a sexual stage and an asexual stage, each necessary to the whole life cycle.

The life cycle of a fern. On the undersides of the older leaves of most of the common ferns, there are brownish scalelike patches which develop as the growing season advances. These are made up of spore cases (sporangia) and the leaf membranes that cover them.

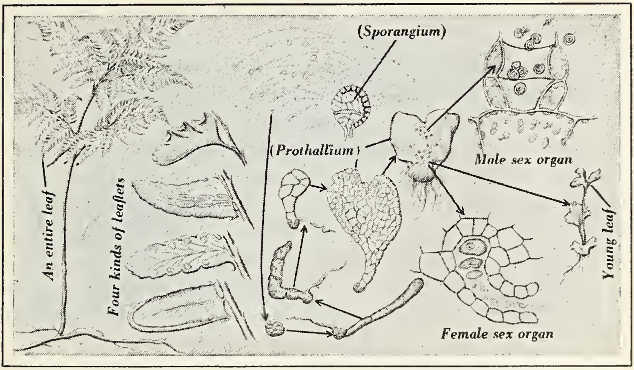


FIG. 387. Reproduction in the fern. The four kinds of leaflets show various arrangements of the spores cases (sporangia). Can you explain the life cycle of the fern from the diagrams at the right?

Each spore case (Fig. 387) consists of a stalk and a capsule in which the asexual spores are formed. The capsules and the spores they contain are so numerous that a single large fern plant sometimes produces hundreds of thousands of spores during a single growing season.

Experiment 86. How do the spore cases of fern scatter the spores? Place a number of ripe spore cases of fern under the low-power objective of a compound microscope, or observe them carefully through a good reading glass. Observe the capsules as they open, until you can answer the question at the beginning of this experiment.

When ripe the capsule, or sporangium, opens in such a way as to throw the spores with considerable force. This action of the sporangia and the currents of air which carry the spores give them wide distribution.

The first cells that are formed when the fern spore begins to grow look much like cells of algæ or of the protonema of moss. Soon the tip cells divide so as to broaden this green growth into a flat heart-shaped body. These small plants sometimes grow in such abundance that they completely cover the moist ground or the surfaces of pots in greenhouses. When they grow on the soil

out of doors, they are not readily seen, and therefore few people ever notice them. From the underside, rootlike extensions (rhizoids) grow downward. The abundant chlorophyll of the young plant makes food manufacture possible, with the result that this stage of the fern can live independently.

The two kinds of sex organs are produced on the undersides of these heart-shaped fern bodies. The male and female sex organs sometimes grow on the same plant, and sometimes on separate plants. Within the male sex structure are a number of very active sperms. The female sex structure, which contains the egg, is partly embedded in the plant. The sperms swim to the egg, and one fertilizes it. The egg is therefore fertilized within the tissue that produced it and remains embedded there.

The fertilized egg does not have a resting period, but starts its growth at once by cell division and enlargement. One part of the developing egg, or embryo, spreads out as a foot or attaching structure which makes close contact with the adjacent tissue. The embryo fern plant absorbs its nourishment, through this foot, from the tissues around it. It soon develops a root, stem, and leaf. This leaf, even when small, may be recognized as like the large and older one upon which the asexual spores developed.

The flat heart-shaped fern body is the gamete-producing, or sexual, stage (gametophyte). The stage of the fern which we ordinarily see is the spore plant, or asexual stage (sporophyte). These alternate in completing the whole fern life cycle. Each generation always produces a spore, which when it grows forms the other generation.

Self-test on Problem XXX–A. **1.** Alternation of generations in animals is found as low in the scale of animal life as the *mollusks.*

2. In alternation of generations each stage resembles its *parent,* but not its *grandparent.*

3. The stage of the fern which produces the male and female sex structures is *wholly* self-supporting.

4. The brownish patches on fern leaves are composed of *sex organs.*

5. The gamete stage of the fern or the moss produces the *gamete-bearing* generation.

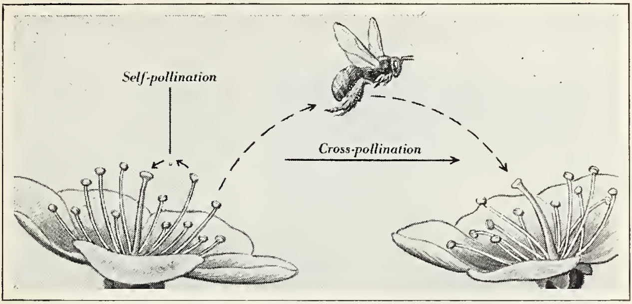


FIG. 388. Using this diagram, can you explain the meaning of "self-pollination" and "cross-pollination"?

Problem XXX–B · What are the Important Aspects of Fertilization and Incubation?

Self-fertilization and cross-fertilization. In those plants and animals in which each individual is either male or female, self-fertilization cannot occur. For example, a female holly or fig tree cannot fertilize itself because it has no pollen from which male gametes may develop. Pollination in plants must precede fertilization, because the male gametes develop from the pollen. Many plants and some animals have both the male and the female reproductive organs on the same individual; in these hermaphrodites self-fertilization may occur. Most plants which are self-pollinated can also be cross-pollinated and cross-fertilized. Some plants that bear both stamens and pistils will reproduce only when cross-fertilized. Other plants regularly reproduce by self-fertilization (Fig. 388).

Wheat is commonly self-pollinated. Certain kinds of tobacco have been improved by self-pollination, at least during several generations. Most plants, however, "run out," that is, produce fewer and fewer seeds or otherwise show signs of diminished vigor, if self-pollination continues for several generations. Some of the reasons for this fact will be discussed in Chapter XXXI. Self-pollination is somewhat more certain than cross-pollination. The violet and a number of other plants bear two kinds of flowers, the familiar large ones which are cross-pollinated by insects, and small

obscure flowers which are always self-pollinated while they are still closed. Thus pollination is certain in these smaller flowers, which produce many seeds, but a sufficient number of seeds result from the cross-pollination of the larger flowers to maintain vigorous stock.

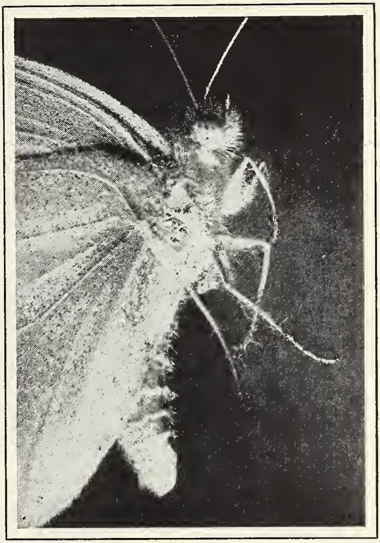
Dr. A. F. Blakeslee

FIG. 389. Which one of the methods of securing cross-pollination is illustrated by these honeysuckle flowers?

*Plants have many interesting structures that prevent self-pollination and secure cross-pollination (Fig. 389): (1) The pollen in some flowering plants ripens and is scattered before the pistil in the same flower is mature enough to permit fertilization of its ovules. (2) The tips of the stamens of some plants open outside, away from the pistil. (3) The stamens of some flowers are too short for the pollen to fall upon the tip of the pistil. (4) Many flowers have colors or odors that attract insects or birds, which in passing from one flower to another may distribute pollen (Fig. 390). (5) The structure of the flower may be such as to force an insect which is entering to get the nectar to brush against the stamens, or the insect in pushing against the base of a stamen may bend the pollen-bearing tip over against its back. When it visits another flower of the same kind, the pollen may be brushed off on the pistil of the other flower.

Relatively few animals are self-fertilized. The eggs of the tapeworm are probably fertilized by sperms from the same individual. The tapeworm, as previously stated, consists of a number of sexually complete individuals joined together in one long ribbon. The eggs of hermaphroditic water animals seem more likely to be fertilized by sperms from the same animal than by those from another animal, since the sperms are discharged into the water at a point nearer the eggs than is likely to be true of those from other animals. In many of these animals, however, such self-fertilization

does not take place, because the eggs and the sperms mature at different times. With hermaphroditic land animals such as the earthworm, the slug, and the snail, the eggs of one individual are fertilized by the sperms of another individual.



Cornelia Clarke

FIG. 390. Note the pollen grains on the moth's wings and feet. Would moths be likely to pollinate day-blooming flowers or night-blooming flowers? Explain

Incubation.[1] All fertilized eggs, whether of plants or of animals, require moisture and favorable temperature in order to develop. Hence no flower seeds would germinate into young plants and no animal eggs would grow into young animals without the proper conditions of moisture and of heat energy. On the other hand, the embryos remain alive within seeds for months, and in certain cases for many years. They may then develop when conditions of moisture and temperature become favorable to germination. Similarly, hens' eggs may be packed carefully and shipped across the entire country without injury to the embryo, provided the egg is not chilled.

There is sufficient heat energy in the water or in the ground where the eggs are deposited to incubate the eggs of the simpler egg-laying animals. The higher egg-laying animals, such as the birds, commonly use the heat energy of their own bodies for incubation of their eggs. A few snakes incubate their eggs by coiling around them. It has recently been reported, moreover, that the

[1] *Incubation* (in ku ba'shun): the process of incubating, or developing an embryo by means of moisture and of heat energy.

body temperature of the female snake rises during such incubation periods. The incubation period for birds varies from fourteen days for the smaller species to three weeks for chickens; four weeks for ducks, turkeys, and geese; and forty to forty-two days for ostriches.

Incubation has many features resembling the internal development of the higher animals. With the few fishes, such as the guppy and the ocean perch, with such reptiles as the garter snake, which produce their young alive, and with all the mammals, the incubation of the fertilized egg takes place within the body of the female.

Self-test on Problem XXX–B. 1. *Self-fertilization* occurs in flowers which have only male or female sex organs.

2. With most plants *self-fertilization* is necessary in order that the succeeding generations of the plants shall be *vigorous*.

3. Describe the structures of plants which secure cross-pollination.

4. *All* hermaphroditic plants and animals are self-fertilized.

5. Fertilized plant and animal eggs develop only when sufficient *heat* and *moisture* are available.

Problem XXX–C · What are Some Unique Behaviors Related to Reproduction?

Premating behaviors. Many of the higher animals have peculiar and often complex instinctive behavior closely related to reproduction. Some male birds and male mammals have mating calls which they make only during the mating season and which serve to attract others of their kind. The "drumming" of male ruffed grouse and pheasants is a mating call. Male birds, such as the turkey, the peacock, and many smaller birds, spread their plumes and strut before the females of their kind. Male deer, elk, and moose are timid during the spring and summer, when their horns are growing and becoming strong. But they become savage and dangerous during the autumn mating season, when their horns have become fully developed. Fighting between males during the mating season is common among Chinese pheasants, wild horses, elephants, rhinoceroses, and many other higher animals. The van-

Astoria, Oregon, Chamber of Commerce

Fig. 391. Catching salmon near the mouth of the Columbia River. Horses are used to pull in the nets. Special Report: The salmon industry of the Columbia River and of Alaska

quished male is either killed or driven away by the victor. The result is that only the fiercest and strongest males become the fathers of the young.

Migration. The migration of some animals, especially certain fish and perhaps the birds, is related to reproduction. Let us consider, for example, the migration of the salmon of Alaska and the Pacific Northwest. The female salmon lay their eggs, which the males then fertilize, in the shallow headwaters of the high mountain streams. Soon after fertilization has been accomplished the old fish usually die or are caught by animals that feed upon them. The eggs develop into a new generation of salmon. While still small and but a few weeks old the young salmon start downstream. After they reach the ocean they are thought to follow fairly definite "trails," sometimes going more than a thousand miles from the mouths of the streams from which they came. They live in the

ocean until mature, a period thought to be three or four years long. Then, as their gametes start developing, they begin the return journey to regions like those in which they began their life. They find their way to the mouths of fresh-water streams, which they enter perhaps in response to the fresh water (Fig. 391). They then swim upstream in large numbers, making great haste and crowding one another by violent swimming. Sometimes the males fight viciously, tearing great wounds in each other's bodies as they hurry onward. When the salmon come to waterfalls, they struggle and jump against the current. The stronger ones succeed in getting over the falls to continue their journey to their breeding regions. As they proceed, their bodies, which were fat when they started, become thin. They hasten to deposit and to fertilize the eggs, then die or soon become easy prey to enemies. Thus the life cycle is completed.

The common eel reverses the story of the salmon. It lives part of its adult life in fresh water but returns to the ocean to reproduce. Later the young slowly find their way back to the kinds of fresh waters from which the parents came.

At the spawning time some fish, such as smelt, travel in great schools which so crowd the mouths of small streams that people are sometimes able to dip them up in great quantities, using dip nets, pails, or even gunny sacks tied over barrel hoops.

As has been stated, some scientists have proposed the hypothesis that there is a relation between the migrations of birds and the development of their gametes; that the birds begin their migrations when their gametes have reached a certain stage of development. Some support of this hypothesis is found in the fact that the spring migration is definitely associated with the return of the birds to their nesting places.

Hibernation in relation to reproduction of frogs and toads. Hibernation of frogs and toads has an important relation to their reproduction. During the summer and autumn they devour and store large quantities of food. At this time their sex organs and gametes are undeveloped, and no reproduction occurs in the autumn. During hibernation the sex cells develop. When the earliest warm weather of spring comes, the frogs dig their way to the surface and at once begin to hunt for pools or ponds as places for

Cornelia Clarke

FIG. 392. *A*, nest of the paper wasp; *B*, leaves from which sections have been cut by the leaf-cutter bee. **Special Report:** How do these insects make their nests?

reproduction. Although their reserve energy is now almost exhausted, the frogs do not hunt for food until their eggs have been laid and fertilized. Experiments in trying to get frogs to feed at this time have been unsuccessful.

Self-test on Problem XXX–C. 1. Many *animals* which are ordinarily timid may become fierce during the mating season.

2. The *stronger* fish are more likely to reach the spawning grounds than the *weaker* ones.

3. The eel spawns in *fresh water.*

4. Salmon spawn in *fresh water.*

5. Amphibia, such as frogs and toads, hibernate during the *spring, after* their gametes have become fully developed.

Problem XXX–D · What are Some Behaviors Related to Care of Offspring?

Nest-building. When we hear the word *nest* we are likely to think only of the home of a bird, because that is the most familiar kind of nest. But if by *nest* is meant any sort of artificial shelter which an animal builds as a place in which to take care of its young, then there are many animals which make nests. However, animals relatively high in the scale of life are the only ones that build nests, since only these take any care of their young.

Many insects, such as the ant, the honeybee, and some of its near relatives, make elaborate nests (Fig. 392). Bees make wax cells of different sizes to accommodate the eggs which are to develop into queens, drones, or workers. Some spiders spin egg cases in which the young spiders live for a time after hatching from the egg. The stronger young spiders eat the weaker.

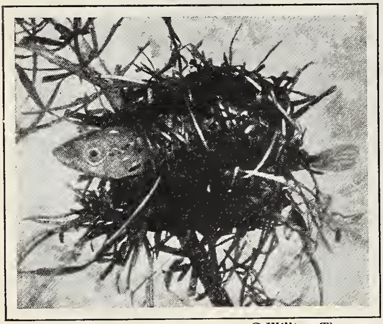


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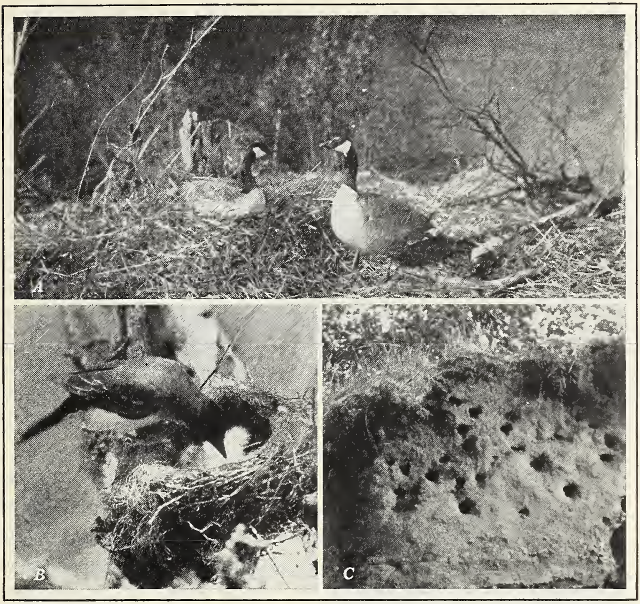
Fig. 393. A stickleback in its nest. **Self-test on Biological Principles:** Using the facts presented in this picture and in the text, can you explain this principle: "The greater the degree of parental care, the less is the need for a great number of eggs or of offspring"?

While most of the fish pay no attention whatever to their young, other than perhaps to pursue and capture them for food, a few species make nests and care for their offspring much as the birds do. When the mating season arrives, the male stickleback (Fig. 393), a small fish common in inland streams and lakes, builds a nest of sticks on the bottom of the stream or pond. He fastens the sticks together with threads secreted from special glands. When his nest is completed, he remains outside to entice the females to lay eggs in the nest. Each female can lay from fifty to a hundred rather large eggs, but she lays only a few in one nest, perhaps only one. As soon as she departs the male fertilizes the eggs she has left and then continues to entice other females until his nest is full.

The male bowfin, or fresh-water dogfish, a fish about eighteen inches long that lives in the quiet waters of the Mississippi Valley and Great Lakes region, builds a nest on the stream bottom by clearing a space with his fins and tail. Bass and sunfish likewise build nests by sweeping a circular depression in the sand or fine gravel. Some kinds of fish use their noses and heads to roll stones about until they have made an irregular panlike area with smaller pebbles in the bottom and around its boundary.

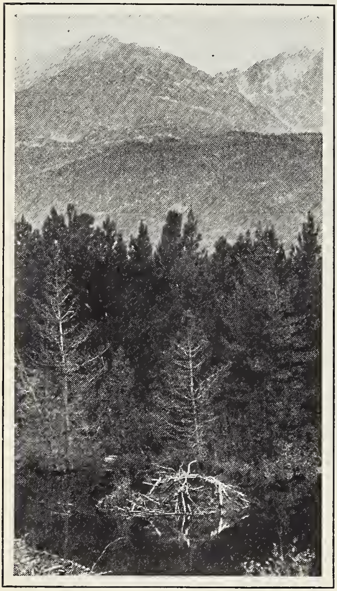


Lynwood M. Chace

FIG. 394. *A*, Hutchins's geese; *B*, kingbird; *C*, tunnels made by claybank swallows. Should you infer that the young of these geese would, when first hatched, be more helpless or less helpless than the young of the kingbird and the swallow? Can you construct the statement of a biological principle which will summarize these facts?

Birds build nests of many shapes and sizes and in many locations (Fig. 394). Most ground birds build rather crude nests on or near the ground. The young of these birds are able to run about and secure their own food almost as soon as they are hatched (precocial birds). Ducks, chickens, and pheasants make such nests. Other birds, the young of which are hatched in a helpless condition, almost naked and blind and unable to feed themselves, build more substantial nests. Such birds (altricial birds) include the robin, red-winged blackbird, oriole, catbird, and the sparrows. The cowbird is a widely distributed native bird which lacks the

nest-building instinct. It lays its eggs in the nests of other birds and allows them to incubate and feed its young.



Denver Tourist Bureau

Fig. 395. A beaver hut in Rocky Mountain National Park. Self-test on Biological Principles: "In order to survive, many organisms must build artificial shelters." How many examples of this principle can you cite?

Sometimes the male bird builds the nest, but more commonly this work is done by the female. When both birds of a pair work at the nest, most of the work is usually done by the female. In the case of the singing birds it is not uncommon for the male to sing in the vicinity of the nest or to fight intruding birds while his more industrious but less musical mate constructs the home for their future offspring.

Few of the reptiles make any sort of nest. Turtles bury their eggs in the sand and allow the earth's heat to incubate the eggs. Alligators sometimes bury their eggs in high mounds which they build of plants and decaying vegetation. This material ferments, thus producing the heat energy needed in order to incubate the eggs.

Mammals, such as beavers and muskrats, field mice, gophers, squirrels, and many others, build houses or dens of one sort or another in which to live and rear their young (Fig. 395).

Kinds of parental care. There is no behavior which could correctly be termed parental care which has been observed of animals lower in the scale of life than the arthropods. Only a few insects care for their young, though they seem to possess the instinct to lay their eggs where there will be suitable food ready for

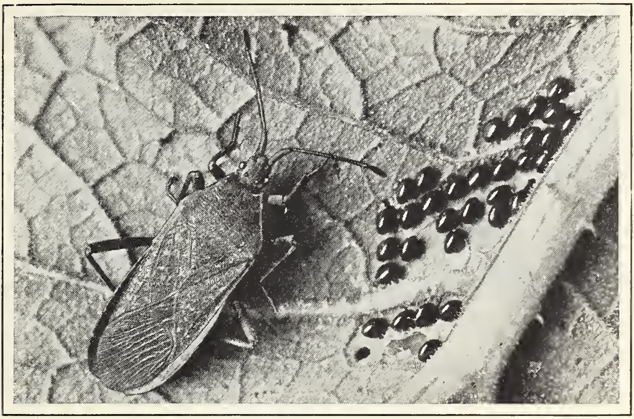


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FIG. 396. Squash bug and eggs. Does this picture illustrate parental care? Explain

the young as soon as they hatch (Fig. 396). The potato beetle usually places its eggs on the leaves of plants of the potato family. The monarch butterfly usually chooses the milkweed plant. In insects such as the mosquito, whose young are fitted only for aquatic life, the eggs are laid in or near the water. Some of the higher insects, such as the honeybee and the ant, give elaborate care to the young, providing them with special food and remarkable attention. The female spiders of some species guard their egg cases until the young emerge, then carry the little spiders about on their backs until the young ones are mature enough to survive without help.

Most of the nest-building fish give some care to their young. The male stickleback and the male bowfin guard their nests until the young are hatched in eight or ten days, and for a few days afterwards. The male bowfin then accompanies them, much like a mother hen with her brood of chicks, and protects them until they have grown to be three or four inches long. There are rare cases of fish that not only carry the eggs in the mouth and pharynx until the eggs hatch but also continue to carry the young fish until they are able to shift for themselves.

Birds furnish parental care of several kinds in addition to incubation. The young of most birds are dependent upon their parents for food. Most of the smaller birds feed their young on various soft-bodied insects or insects in the larval stage. The larger birds, such as eagles and hawks, feed their young upon small mammals and other birds which they capture. The large and hungry mouths of young birds seem to be always ready for more food. One robin was observed to bring four worms at one time. She gave one worm to each of her four young birds, which promptly stretched up their necks and opened their mouths begging for more food. A few kinds of birds, such as pigeons and doves, feed their young by the use of food which the parents have swallowed and partly digested or by the use of a secretion called crop milk, which is produced within the parent's digestive system. Until the young birds leave the nest, and in many species for a considerably longer time, the parent birds protect their young, to keep them warm and to shelter them from rain (Fig. 397). It is an amusing sight to see a mother hen attempting to cover her lusty youngsters after they have become so large that she topples upon their heads and backs scarcely able to get a toe on the ground. Birds, as well as the mammals, will often fight bravely for their young. You have perhaps observed a squirrel running from the nest he started to rob, while the parent birds pursue him, driving him to greater haste with frequent vicious pecks. Robins have even been known to attack children near their nests. A mother hen was observed to kill a harmless garter snake which had the misfortune to glide near her brood of chicks. She rained blows with her beak upon the snake's head and gave sharp cries of warning to her chicks, which stood about her in a circle, their necks stretched forward while they uttered subdued chirps of alarm.

Lynwood M. Chace

FIG. 397. Killdeer on the nest. State a biological principle which is illustrated by this picture

The male mammals of some species share with the females the work of caring for the offspring. This is not true of all mammals, however. The male cat, for example, would eat his offspring were it not that the mother cat, which becomes especially fierce when her kittens are young, fights him away. The male horse, or stallion, however, fights valiantly to protect his herd and has been known to put to flight a bear or a panther which was attempting to steal a young colt.

Length of period of parental care. Different kinds of birds require different lengths of time to grow to their mature size. Young robins may grow so rapidly that they may be ready to fly from the nest in ten days, though usually about two weeks are necessary. Chickens, turkeys, and geese require six to eight months, and the ostrich may require two years or more to reach full maturity.

Many young mammals, such as kittens, pups, and baby mice, are born blind, and all mammals are more or less helpless at birth. Their digestive organs, muscles, bones, sense structures, and nervous systems are far from being mature. Even if they could secure meat or plants, they could not then use them as food. The young mammal, unlike the young frog or turtle, could not survive without the care of its mother. She furnishes it with milk for food and with shelter, warmth, and protection.

A longer period of parental care increases the chances for the survival of each individual, and consequently a smaller number of young will maintain the species.

Self-test on Problem XXX–D. 1. The simplest animals *rarely* build nests.

2. *No* fish build nests.

3. Reptiles which build crude nests are __(?)__ and *alligators.*

4. Few of the *mollusks* have been observed to care for their young.

5. The lowest chordates which have been observed to care for their young are some of the *reptiles.*

6. Some *male* mammals will fight for their young, while other *male* mammals will devour their offspring.

Self-test on Biological Principles. What evidences can you find in the story of the salmon migration which tend to prove "the survival of the fittest"?

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Why does a female stickleback or a female dogfish not need to lay so many eggs as a cod or an eel?

2. Why is it of more advantage to Amphibia, such as frogs and toads, and to insects, such as butterflies, to lay their eggs in the spring rather than in the winter?

3. In what ways is the incubation of birds' eggs like that of frogs' or toads' eggs, and in what ways is it different?

4. Plants brought into a new region often grow very well but do not produce fruit. What possible explanations can you offer?

Exercise on Scientific Method (Weighing Facts). The young of several of the mollusks, such as the clam and the fresh-water mussel, undergo part of their metamorphosis while protected within the shell of the female. Is this protection true parental care? Justify your answer.

Project 24. To collect fern spores and grow fern plants. Secure an earthen brick which will readily absorb water. Immerse it in water, and while its surface is still wet hold it close to a fern plant the leaves of which have ripe spore cases. Shake the leaf, then stand the brick with one end in a dish which contains two or three inches of water. Keep the dish and brick in a warm place which is neither in direct sunlight nor in darkness. After a few days watch for young fern plants and learn what you can about how they grow. Why is the brick to be kept standing in water? Why is it placed in a medium-lighted warm place? How many days is it before the first green growth can be found? How many days until a fern leaf can be found?

Special Reports. 1. Alternation of generations takes place in all flowering plants, but the sexual generation is not easily observed. The entire development of the sexual generation takes place within the structures of the flower. Study this topic in an advanced botany or biology text and prepare a class discussion of it.

2. What other devices for securing cross-pollination can you find by examining flowers or by reading descriptions in botany textbooks?

3. Not all Amphibia lay their eggs in water, as do the common frogs, toads, and salamanders. How do the Surinam toad, the lungless salamander, and the obstetrical frog take care of their eggs? Perhaps an encyclopedia will provide the needed information.

4. How is a queen bee made from a worker larva? What are the ant "nursemaids"? You can find discussions of these topics in an advanced zoology or entomology or in an encyclopedia.

Chapter XXXI · The Factors of Inheritance

Questions this Chapter Answers

To what extent and in what ways may offspring of the same parents differ?

What are the structures that control inheritance?

What are Mendel's laws of inheritance?

Are acquired characters ever inherited?

How has man applied the laws of inheritance in improving plants and animals?

Do the Mendelian laws apply to human inheritance?

Problem XXXI–A · How do Plants and Animals Change?

No two alike. It is not unusual to find twin boys or girls who look so much alike that only those who know them best can tell them apart. Usually, however, twins have distinguishing characters [1] that will be noted by careful observation. Slight differences, such as those in structure or in voice, in ways of walking, or in eye movements, may be noted. Probably no two individuals are ever exactly alike. Moreover, when the large number of characters which might vary are considered, it seems strange that plants and animals of the same kind are as much alike as they appear to be. Yet there are more ways in which individuals of the same kind resemble one another than in which they differ (Fig. 398). When studying unknown plants and animals, however, one finds that the individual variations often make it difficult to determine correctly the species to which an animal or a plant belongs.

Extent and nature of variation. Since a plant or an animal is made up of different parts, features, or characters, variations may appear in one or more of these characters. Thus some of the dogs that are of the same litter may have pointed ears and some may have blunt ears; some may have short legs and some long legs;

[1] *Character* (kar'ak ter): any characteristic, such as size, color, length of limb, and so on.

FIG. 398. Twin moose calves in Riding Mountain National Park, Manitoba. Name several ways in which these similar animals would be likely to vary

some may have long noses and some short noses; some may be black and some white; some may grow rapidly and others slowly. If all those that have blunt ears should also have short legs, short noses, be black, and grow rapidly, while all the others should have the opposite characters, then the dogs of the same litter would appear almost like two distinct species. But the variations may be distributed in other ways. That is, one large white dog may have a short nose, pointed ears, and short legs, and may grow rapidly. Another large white dog may have a long nose, pointed ears, and short legs, and may grow rapidly. Other combinations of these five qualities, characters, or factors may occur. Then there are many other factors besides color, rate or extent of growth, length of nose or of legs, and shape of ears which may vary with each dog.

* **Slow changes through slight variations.** With the many variations that occur in nature some fit the demands of the surroundings and some do not. While ordinarily variations among individuals of the same kind are slight, nevertheless a slight variation may mean survival or death to the plant or animal possessing it. For example, if it occurs that the only animals that can reach their food are those that vary so as to be taller, the shorter ones will be less likely to survive in the struggle for food energy. The taller

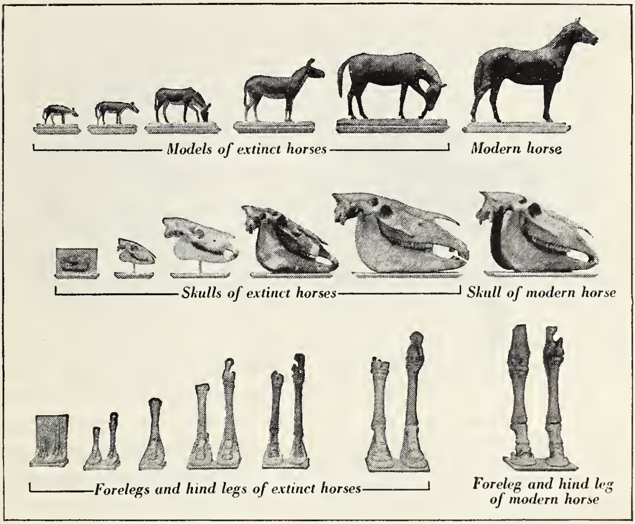

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Fig. 399. The slow development of the horse. Trace the changes in the structure of the foot from the primitive horse to the modern horse. Should you infer that the habitat of the modern horse is the same as that of the primitive horse?

ones therefore will be more likely than the short ones to reproduce. Again, in the succeeding generations there will probably be an increasing proportion of tall individuals, because most of the short ones of each generation will starve to death and will not reproduce. Under such conditions there might develop through many succeeding generations only tall animals of this kind, because the short ones would not live to reproduce their kind. Thus what appeared as a variation might sometime become established as a fairly constant character of this kind of animal. At the end of a long period of time, moreover, the animals might be very different from their remote ancestors. Yet those of any given generation would seem but little different from those of either the preceding or the following generation.

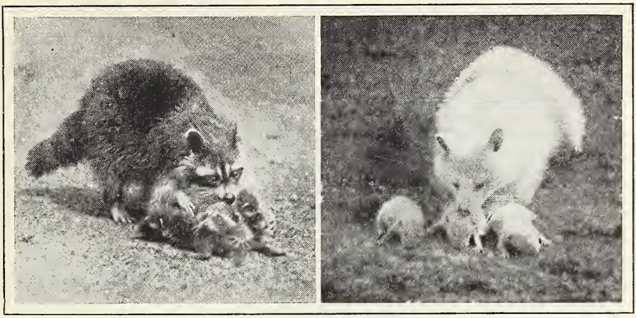
Fossils have been found which show that many of our common animals have changed slowly through the ages. The first horses

are believed to have been five-toed animals no larger than dogs (Fig. 399). They lived in the swampy forests. Fossil bones show that in later periods the horse had three toes on the hind feet and four toes on the front feet. This horse was somewhat larger than its early ancestors. It lived on the grassy plains of central North America. As the ages passed, the hind toes became shorter and finally disappeared. The modern horse stands on the very tip of the middle toe. The only remaining evidences of the other toes are the splint bones in the leg of the horse.

Fig. 400. A six-legged frog. An animal or plant which varies considerably from others of its kind, but which does not transmit the difference to its offspring, is called a freak. How could one determine whether this frog is a freak or a mutant?

***Mutants and mutation.** Variations in living things of the same kind are not always slight. Once in a while one or more of the characters of a given plant or animal vary from the usual to such an extent that the new individual looks very different from any others of its kind (Fig. 400). If the new character is inherited by the offspring of the changed plant or animal, the character is called a mutation, and the individual in which the mutation first appeared is called a mutant. Hornless, or polled, cattle did not develop by a gradual shortening and final disappearance of horns through succeeding generations. This quality, or character, appeared suddenly and has occurred as a mutation more than once. Calves were born without the "horn buttons" from which horns are formed; hence no horns developed. Thus the different types of hornless cattle have become established through mutation.

A mutation may consist of the loss of some character which is normally possessed by the species of animal or plant to which the mutant belongs, or it may consist of an additional character. An example of a lost character is color in such mutants as white crows,



Lynwood M. Chace   Ben East

FIG. 401. These mother raccoons are gently carrying their helpless babies back to the nest. How does the picture prove that the white mother raccoon is a true mutant?

white blackbirds, white rats, and the like (Fig. 401). An example of an added character is an extra finger which is found on the hands of some people. Like the small variations, mutations may give the organisms possessing them a better or a poorer chance to survive than the normal individuals have. For example, if the mutation be a conspicuous color, the individual may more easily become prey to enemies. But if the mutation be better protective coloration, the individual may more easily escape the enemies of its kind.

The difference between variations and mutations, though not fully understood, seems to be chiefly one of the amount of change in the offspring as compared with its parent. A mutation is a sudden appearance of a character and is not the result of generations of accumulating slight variations. A suggested explanation of these facts is given later.

Producing new kinds by crossing. When pumpkins and summer squashes are grown near each other, the pollen from one may be deposited within the flowers of the other. It is likely that pollen from other neighboring plants, as ragweeds, corn, apples, and strawberries, may also fall upon the same stigma. But the pollen from plants so distantly related as corn and apples will not grow so as to fertilize the eggs within the embryo sacs of the summer squash. Summer squash and pumpkin plants, however, will each

fertilize the other. These statements illustrate the fact that distantly related plants and animals cannot be crossed. But closely related plants and animals may unite even though they do not belong to the same species, or sometimes even to the same genus. There is no hard-and-fast rule regarding the extent of relationship over which crossing may occur.

Canada Department of Interior

Fig. 402. Catalo, a hybrid produced by a Hereford cow and a buffalo. For what purposes might man produce hybrids such as this?

* When summer squash and pumpkin plants are crossed, or interbred, one might expect that one half of the total number of the resulting fruits would be pumpkins and one half would be summer squashes. He would be wrong. It is the egg from one kind of plant and the sperm from another kind of plant which have united. The embryo plant thus produced has some of the characters of each parent plant. Therefore the resulting fruit is partly summer squash, partly pumpkin, yet neither. It is not suitable for use either as pumpkin or as summer squash. New organisms that are produced by crossing related but different kinds of parents are called hybrids.

One of the best-known and most useful animal hybrids is the mule. It is produced by crossing the female horse and the male donkey. It is possible, but unusual, to use the opposite cross. The mule has many of the characteristics of the donkey, but has more nearly the size of the horse. It has greater endurance for work, extremes of temperature, and other hardships, is more sure-footed, and can live on rougher food than the horse.

A hybrid usually resembles its parents sufficiently to make its relations to them fairly clear. Yet usually it is obviously different from either. A hybrid may be either superior or inferior to both its parents in some of its qualities (Fig. 402). Some of Burbank's best new kinds of plants are hybrids. Plant and animal breeders are constantly watching for hybrids that possess superior qualities.

Certain plant and animal hybrids do not produce offspring. Such hybrids can therefore be secured only from the original cross.

Differences produced by surroundings. It should be clear to all that some of the differences between organisms of the same kind are not due to inheritance but to nutrition, to use, or to various other conditions of the environment. Thus one twin brother may become an artist and the other a blacksmith. As a result of the differences in the kinds of work the two men do, they will become more and more different in physical development. If two plots of corn from the same stock are planted in places as much alike as possible in every way, one with many plants crowded into the area, the other with few plants, the crops from the plots will be very different (Fig. 403).

Dr. A. F. Blakeslee

FIG. 403. What environmental factors might account for the differences in these two plots of corn grown from the same stock?

Animals of the same ancestral stock will develop very differently if kept under conditions which are similar except that one or more of the food factors are different. But similar care will fail to produce similar animals if the inheritance of the animals is very different.

*It must be clear that the ancestral stock determines what are the possibilities of development of new organisms, but that such environmental factors as food, light, water, space, sunshine, and relation to enemies determine whether the inherited possibilities are developed. Even the best environment cannot produce high-grade organisms from individuals which carry no good ancestral stock. Knowing this, the wise animal and plant breeder secures the best breeding stock he can find.

Self-test on Problem XXXI–A. **1.** Twins are *often exactly* alike.

2. Differences in weight furnish an example of *variation.*

3. Variations are *never* of great importance in the struggle for survival.

4. Such marked variations between one generation and the next as changes in the number of toes are known as *hybridizations.*

5. Slight *mutations* may be observed in the offspring of almost every kind of animal or plant.

6. It is not *likely* that rose plants and cabbage plants could be successfully crossed.

7. A cross between a dog and a wolf would be an example of a *mutant.*

8. The environment has *little* influence upon the development of an organism.

9. Heredity has *little* influence upon what the adults of the next generation will be.

Problem XXXI–B · In What Respects is the Cell the Basis of Inheritance?

What one cell carries. We have seen many illustrations of the fact that each living thing has grown from one cell. It must be true, then, that all the hereditary[1] qualities or characters of each living thing at its beginning were held in one cell or that they have developed from that one cell. Why a particular fertilized egg cell grows and becomes a horse and not an oak tree seems hard to understand. This phenomenon[2] is especially perplexing when we remember that the fertilized egg cell may be so small that it must be magnified two or three hundred times before it may even be seen. Yet this small fertilized egg contains whatever it is that causes its development to result in a horse or an oak tree, a monkey or a giraffe (Fig. 404). In a similar way this cell carries whatever it is that makes the inherited differences between the various kinds of oak trees, the different kinds of roses, or the different human beings.

Such a fertilized egg cell in no way resembles the appearance of the adult plant or animal into which it may grow. Yet structures within it determine whether the animal it becomes may

[1] *Hereditary* (he red′i ta ry): having to do with inheritance.

[2] *Phenomenon* (fe nom′e non): any happening or occurrence.

FIG. 404. Each of these plants and animals grew from a single cell. Is this also true of simpler plants and animals? Can you state these facts in the form of a principle?

have feet with claws, and may climb trees in search of food; whether the animal may have feet with cloven hoofs, and may browse on pasture grasses; or whether the animal when developed may study about nature's laws. These cell structures determine whether the plant produced may bear roses or corn, or may become a giant California redwood. These structures, called chromosomes, are in the nucleus of the fertilized egg cell. These, as will be explained, determine what the developing organism shall be.

Cell division. In order that an organism may grow or that new cells of any kind may be formed, it is necessary for cell division to take place. The chief structure concerned in cell division is the nucleus. Within the nucleus of every cell there is granular material (chromatin). As the nucleus of any cell starts the process of division (mitosis), this granular material combines and forms a ribbon, or band. This band soon can be distinguished as composed of short rods, which are the chromosomes. The number of chromosomes formed in the body cells is the same for all dividing body cells of any particular kind of plant or animal. Thus every body cell of the lily always has twenty-four chromosomes; of one of the parasitic worms, two chromosomes; of the crayfish, two hundred; and of man, forty-eight. When the cell is in process of dividing (Fig. 405), each chromosome splits lengthwise. The newly formed chro-

mosomes are drawn to opposite ends of the dividing spindle, one half to each end. These now form the two new nuclei, each one of

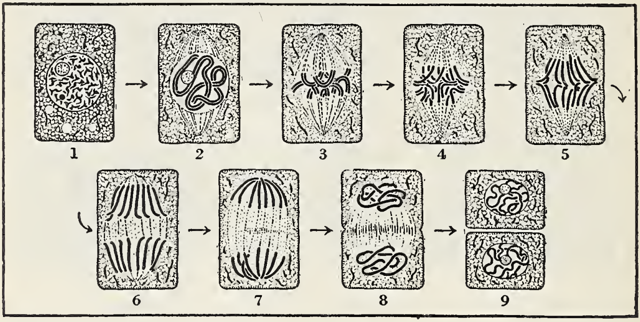


FIG. 405. Cell division (by mitosis). Organize a short report to explain this figure

which is composed of as many chromosomes as were in the parent cell. The cytoplasm is then divided by a new cell wall. In due time the new cells may in their turn divide as their parent cell did.

It is easy to see that by this process the number of chromosomes in all the cells of an organism is kept the same. It might be expected therefore that when a sperm nucleus and an egg nucleus unite, the chromosome numbers would be doubled in the fertilized egg. A peculiar occurrence prevents this doubling of chromosome numbers. In one of the stages in the development of sperms and eggs the chromosomes do not split. Instead the chromosomes, without splitting, are separated into two groups at opposite ends of the cell. Therefore, when the cell completes its division into two cells, the new nuclei of the mature reproductive cells are formed of one half the number of chromosomes that are found in the body cells. When an egg is fertilized by a sperm, and the nuclei of the egg and the sperm have united, the chromosome number is again the regular number of the body cells. Thus the fertilized egg has received half its chromosomes from each parent.

It must be kept in mind that the chromosomes carry the inherited characters. The fertilized egg does not carry all the ancestral characters of both parents, since only half of the chromosomes of each parent cell were used in forming the nucleus of the fertilized

egg. It does, however, include chromosomes that carry some ancestral qualities from each parent. Furthermore, since both parents once came from their parents in the same manner, and since their chromosomes carried the characters of their ancestors, it follows that the young generation has chromosomes that have been derived in part from many generations of ancestors.

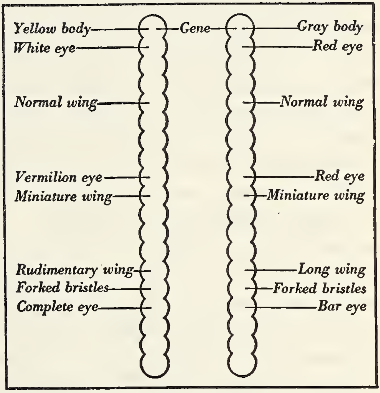


Fig. 406. Diagram of a pair of chromosomes of the fruit fly (*Drosophila*). The location of the genes named here has been determined by many experiments. What facts concerning genes can you infer from this picture?

The nature of genes. Chromosomes are not simple structures. It is thought that each chromosome consists of many parts, each part probably being responsible for certain hereditary characters (Fig. 406). These parts, or units, are called genes (see Glossary). One pair of genes may control body color, another may control eye color, each one of others may control form of nose, ear, chin, thumb, body height, tendency regarding fatness, and so on for the many hundreds of hereditary characters. Possibly one gene may control more than one character. The entire theory of genes is relatively new and is receiving much careful study. Since no other theory so well explains the observations that have been made, biologists now speak of the existence of genes as a proved fact. It must be recognized, however, that their existence has not been proved with a certainty which can be compared to that regarding chromosomes.

Strong and weak genes. The genes related to corresponding characters seem to differ in their relative influence. Thus if two parents have red hair and if their ancestors for many generations have had red hair, it is likely that all their chromosomes carry genes for that color of hair. If, however, one parent has black hair,

likewise his parents for several generations, his chromosomes probably carry the gene for black hair color. When this gene appears in association with the gene for red hair color, will the hair color be part black and part red, or a shade made by blending black and red, or will one color prove to be stronger than the other and dominate, or prevail over, it? The fact is that in animals black does sometimes dominate, or prevail over, other colors and sometimes does not. When one character carried by a gene is stronger than its corresponding character carried by another gene, the strong one is called dominant, and the one that is hidden is called recessive.

Genes, variation, and mutation. Since the two sets of chromosomes that are in a fertilized egg have come from different lines of parentage, it is clear that new hereditary combinations exist in each new organism. The only exception to this statement occurs when a fertilized egg is itself separated into two or even more parts in some way so that each part develops into a separate individual. Such a division results in so-called identical twins or triplets. You have doubtless noted that twins are of two kinds. There are those which are of the same sex and resemble one another very closely in many ways. These have both developed from the separation of a single fertilized egg. Then there are twins which resemble in about the same ways as other brothers and sisters. These have developed at the same time from two fertilized eggs. The differences are produced by the different genes in the chromosomes. Variation between related living things is to be expected, since new combinations of genes produce new results.

Experiments have been made by treating the reproductive cells with X rays. It has been found that if the cells are treated too severely or too long the chromosomes may be killed. If, however, they are treated carefully and for a short time some of the genes are changed, though the whole chromosomes may not be killed. The union of a sperm and an egg, thus treated, is likely to result in a mutant, since some genes which the chromosomes of the parents originally carried will not appear in the next or in succeeding generations.

It has also been found that chromosomes sometimes may become tangled or attached to one another. At such times it is thought possible for genes to become transferred from one chro-

mosome to another, or for various combinations of genes to be made. Such occurrences would of course make differences in the hereditary characters appearing later in organisms produced by the chromosomes. Therefore variations result not only from combinations of the genes that come from the two parents but also sometimes from shifts of the genes within the chromosomes.

Self-test on Problem XXXI–B. 1. The structures within a fertilized egg which determine what the developing plant or animal shall be are called *chromosomes.*

2. The chromosomes within the cytoplasm of a cell are made up of granular material called __(?)__.

3. A human embryo has received an *equal* number of *chromosomes* from both parents.

4. The units of which chromosomes are supposed to be composed are known as *chromatins.*

5. An investigator crossed garden peas having white flowers with those having red flowers. All the resulting plants had red flowers. Therefore in this case red was a *recessive* and white a *dominant* character.

6. Sometimes variations are thought to result from exchanges of *chromosomes* between *genes.*

Problem XXXI–C · What are the Laws of Inheritance?

Laws of inheritance. The discovery of some important laws of heredity was made in the beginning of the second half of the nineteenth century by Mendel, an Austrian monk. As a result of experimenting with garden peas, Mendel found that such characters as tallness, shortness, smooth seeds, or wrinkled seeds bred true from generation to generation if the parent peas were grown and kept separate from one another. After making sure of pure strains of pea plants for seven contrasted characters Mendel experimented in producing hybrids by crossing plants with contrasting characters. Thus he crossed tall with short plants, and those having smooth seeds with those having wrinkled seeds, and so on. When he crossed tall with short plants, Mendel found that all the plants in the next, or F_1, generation were tall. Mendel concluded that tallness is stronger and is dominant over shortness. He therefore called tallness a dominant character, and shortness a

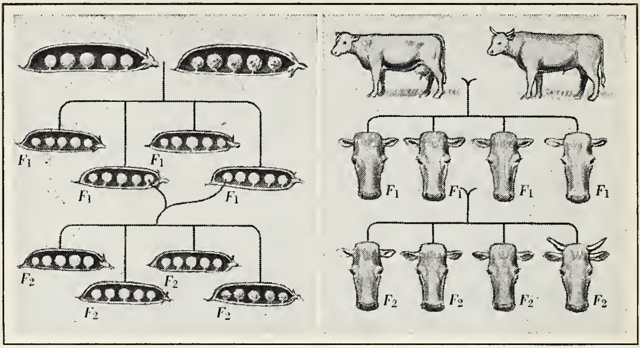


Fig. 407. Crossing smooth and wrinkled peas, and horned and hornless cattle. Can you explain the results in the F_1 and F_2 generations?

recessive character. Among the facts he established by similar experiments are that smoothness is dominant over wrinkledness in the seeds (Fig. 407); yellow is dominant over green in the cotyledons; green is dominant over yellow in unripe pods; and red is dominant over white in flowers.

Mendel experimented further to find whether recessive characters would appear again in succeeding generations. He crossed with one another the tall peas of the first hybrid, or F_1, generation which had been produced by crossing the pure-bred tall and pure-bred short parents. We must keep in mind that in these plants the genes for shortness are present but are dominated by those for tallness. In the next, or F_2, generation Mendel found that approximately one fourth of the plants were short like the short grandparent, and approximately three fourths were tall like the tall grandparent. In experiments regarding the others of seven contrasted characters Mendel found about the same proportions between the dominant and recessive characters in the third, or F_2, generation. That is, in the third generation of such hybrid crosses the recessive character reappears in approximately one fourth of the cases, and the dominant character in approximately three fourths of the cases.

By crossing with one another the F_2 recessive-character plants.

that is, the short plants, Mendel secured nothing but recessive-character plants, or short plants, in succeeding generations. It was

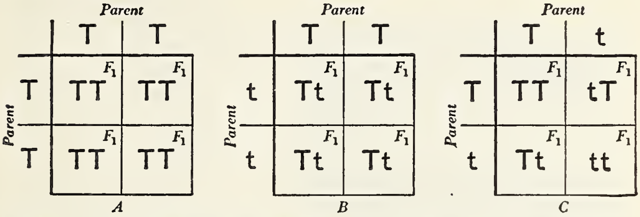


FIG. 408. *A*, if both parents carry only genes for tallness (T), all their offspring (F_1) will be tall. *B*, if one parent carries genes for tallness (T) while the other carries genes for shortness (t), all their offspring (F_1) will be tall hybrids. *C*, if both parents are hybrids, that is, have genes for both tallness (T) and shortness (t), one fourth of their offspring will be pure tall, one half will be hybrid tall, and one fourth will be pure short. Can you make figures similar to this to illustrate 3, *b*, and 3, *c*, of Mendel's laws, p. 628?

clear that the recessive character alone was present in these F_2 plants, that is, they were pure short plants and would breed true as short plants. But when the tall plants of the F_2 generation were crossed with each other, the succeeding generations consisted of some tall and some short plants. These results showed that the tall plants of the F_2 generation were not all pure tall plants, but that some at least of the tall plants were hybrids. Later experiments have proved that the F_2 generation consists of approximately one fourth pure tall plants, one fourth pure short plants, and one half hybrids. These proportions would usually be strictly correct only when large numbers are considered. In many cases, however, the proportions have been found true even when small numbers of individuals were used.

***Summary of Mendel's laws.** Mendel's experimenting resulted in these laws of heredity:

1. *Law of unit characters.* Unit characters will breed true from generation to generation if the parent stock is pure for this character (Fig. 408, *A*).

2. *Law of dominance. a.* When an individual which is pure for a certain character (for example, tallness) is crossed with another which is pure for a contrasting character (for example, shortness), the offspring will all have the one of these characters (tallness) which is dominant over the other (Fig. 408, *B*).

b. These offspring are hybrids which carry the genes of the recessive character as well as those of the dominant one.

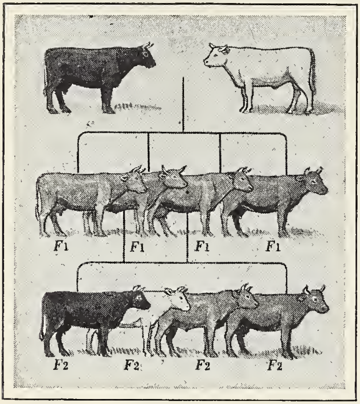


FIG. 409. Incomplete dominance. State which of Mendel's laws this figure illustrates. Is the white cow in the F_2 generation pure for the character whiteness?

3. *The law of segregation.* *a.* When hybrids are mated, approximately 25 per cent of the offspring are pure dominant, 25 per cent pure recessive, and 50 per cent hybrid (Fig. 408, *C*).

b. When pure dominants are mated with hybrids, approximately 50 per cent of the offspring are pure dominant, and 50 per cent are hybrid.

c. When pure recessives are mated with hybrids, approximately 50 per cent of the offspring are pure recessives, and 50 per cent are hybrids.

Further illustrations of inheritance. Since Mendel's results were first made public, many experiments have been made. These have confirmed the principles of inheritance which he established. When Mexican black corn and white corn are crossed, the color of the grains on an ear may be counted to determine the accuracy of the Mendelian proportions. In the cases of some inherited characters it is now known that the genes are equally potent or nearly so, with the result that neither is dominant nor recessive. Thus the children of Negro and white parents are usually less dark than one parent and darker than the other. Red and white cattle when crossed produce roan offspring (Fig. 409).

Acquired characters not inherited. If white cats were frequently washed and kept white, the washing might add to their beauty but would in no way increase the chances of natural whiteness in future generations. Or if these white cats were frequently dipped in black or red ink, that treatment would in no way change the color of their offspring. The color inheritance could be changed only by changing the genes in the chromosomes of the reproductive cells.

*We may select individual plants or animals that are particularly well suited to our needs and wishes, and may keep these selected individuals in the best possible environment, but they transmit to their offspring only the characters they themselves inherited. They cannot to the slightest extent transmit to their offspring any character as it has become modified as a result of the care which they themselves received.

Many good illustrations may be cited showing that *changes* in characters resulting from experience are not transmitted. Young sheep have long tails, but as a sanitary measure farmers for many centuries have cut off the lambs' tails. Young lambs appear with tails undiminished in length. A great tennis player may practice and play for twenty or even thirty years. His children may inherit his fine physique, good eyes, and sound heart, but they inherit none of his ability to play tennis. They may inherit the qualities that permit them to learn to play tennis. We sometimes hear it said that ability to perform excellently in music is inherited, and the several generations of musicians in the famous Bach family are cited as proof. It was the capacity or ability to learn music that was inherited. The home and community musical environment helped to develop this capacity that had been biologically transmitted.

Some people believe that children can inherit characters that are caused by special experiences their parents have had. For example, some mothers play the piano and sing beautiful songs so that unborn children may become musicians. The children may show musical talent; but, if so, the reason is that they have inherited musical talent, and not that they have acquired it as a result of their mothers' playing and singing. In other words, capacity may be inherited; but musical experience cannot be inherited. Another example is furnished by the belief sometimes held that a bad fright given a mother before the birth of her child may make the child abnormal[1] mentally or physically. Such claims are entirely without scientific foundation. It is known that birthmarks are caused by abnormal growth of certain tissues. There is no scientific evidence that birthmarks are caused by frights the mothers may have had.

[1] *Abnormal* (ab nor'mal): not normal; atypical.

Self-test on Problem XXXI–C. **1.** Some important early scientific investigations of the laws of inheritance were carried on by (1) Tyndall, (2) Mendel, (3) Burbank, (4) Pasteur, (5) Lister, (6) Aristotle.

2. If garden peas with red flowers are crossed with garden peas with white flowers, *one half* the plants in the F_1 generation will have white flowers, and *one half* in the F_2 generation will have white flowers.

3. All the offspring of two black cats *will* be black. Explain.

4. It would be *impossible* for the offspring of animals having distinct colors to be of a shade somewhere between the colors of the parents.

5. If all kittens had their tails cut off, the kittens of *some* future generation would be born without tails as a result of this treatment of their ancestors.

6. Unusual experiences of a mother before the birth of her child are believed by scientists to have *little* effect upon the bodily appearance of the child.

Problem XXXI–D · How do Men Apply the Laws of Inheritance?

Selection and development of the best. Often human beings are the determining factors that decide which plants and animals will be selected or rejected. For example, suppose there are four kittens in a litter, two white and two black. If only two may be kept and if white cats are preferred, the white kittens are kept and the others are disposed of. This selection increases the probability that white kittens will appear in future, because the genes causing whiteness will be transmitted to the offspring. Man's applications of the known laws of inheritance have effected great improvements both in the quality and in the quantity of the plants and animals upon which men depend. Most of our domestic plants and animals have been developed from smaller or otherwise less desirable wild varieties (Fig. 410). Corn was cultivated by the Indians when white men first came to America. Probably the Indians had, by selection, produced corn somewhat different from the wild variety and probably somewhat better. But the Indian corn had short ears and small grains. By careful selection, crossbreeding, improved cultivation, and continuous care in using the best types for succeeding years, man has produced superior varieties of corn with large ears and grains. It has been possible to produce short

cornstalks with early-maturing, though smaller, ears for use in northern regions where there is a short growing season; also, tall stalks with large ears for use in regions with a longer growing season. It has likewise been possible to select other qualities of corn and by selection in successive years to develop kinds of corn for special purposes. For example, there is one kind of corn which produces a high percentage of oil, and another kind which produces a small percentage of oil and a high percentage of starch. If a farmer were to order from a seed-corn salesman a bushel of his best seed corn, the salesman, before filling the order, might inquire: "Do you wish to raise corn for general farm uses, for selling to a factory which makes starch, or for selling to a factory which makes corn oil? And where do you propose to raise corn, in Missouri, in North Dakota, in Iowa, or elsewhere?"

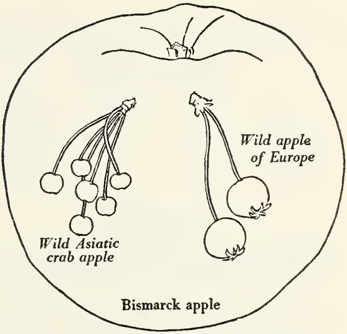


FIG. 410. The large domestic apple was produced from the small wild apple of Europe. Can you name other plants that have been improved?

One of the significant achievements of modern plant-breeding and animal-breeding has been the development of types immune to certain diseases. In a wheat field that was badly infected with rust a few stalks that were not affected were discovered. The grains of these plants were saved and planted. Fortunately they bred true for this character of resistance to rust. It has since been possible by crossing this type of wheat with other desirable types to produce wheat which gives a high yield per acre and is also less affected by rust than other wheat. In a similar fashion man has produced corn which is immune to smut, cabbage which resists the deadly disease known as the yellows, and potatoes which are immune to blight. Partial success has been achieved in producing animals immune to certain diseases. Texas fever kills thousands of cattle every year. It was found that certain cattle from India

are immune to the fever. By crossing the Indian cattle with common cattle a variety has been produced which is a good beef animal and is also immune to Texas fever.

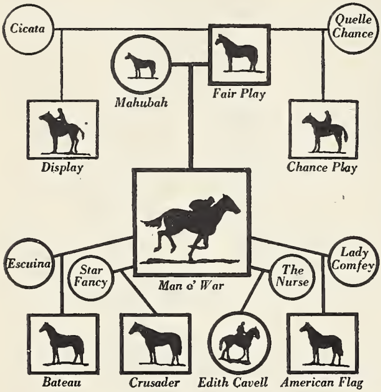


Fig. 411. The horses pictured in black were famous race horses.[1] Explain how this diagram shows that desirable traits are inherited

*The methods of the plant-breeder or animal-breeder include (1) improving known species by selecting and breeding desirable types, (2) producing new types or new varieties which may possess entirely new combinations of characters, and (3) preventing the breeding of undesirable types. Luther Burbank used all these methods in producing the many improved types of plants which he gave to the world. In a field of thousands of plants he often found only two or three which possessed any indication of the desired characters. These he kept for further breeding; all others he destroyed. Thus by selective breeding through a period of years Burbank produced many of our choicest and most valuable fruits, flowers, and other useful plants.

Animal-breeders use the same principles in developing domestic animals for particular uses. When a breeder wishes to know more about a plant or an animal than can be seen merely by looking at it, a written record of its ancestry is desirable. Such a record, or pedigree, usually covers several of the characters regarded as most important for the animal or plant concerned. The pedigree of a particular kind of wheat gives the record for each generation regarding such qualities as number and kind of grains, total yield, vigor of the growing wheat plant, and its resistance to disease, drought, or cold. The pedigree of a draft horse deals with such important characters as weight, form, disposition, endurance, and

[1] From Caldwell, Skinner, and Tietz's *Biological Foundations of Education.*

working qualities. The pedigree of a race horse deals with speed, endurance, disposition, and action during races (Fig. 411). Nearly all kinds of animals and plants used in man's domestic life are now pedigreed in one way or another, but plant pedigrees have not been developed so extensively as have those for animals, though people are coming more and more to recognize their importance.

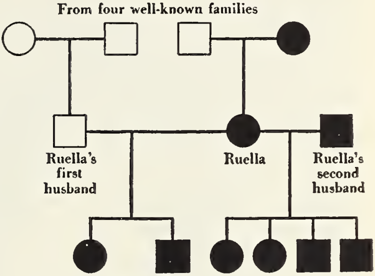


FIG. 412. A study of feeble-mindedness. Circles represent females; squares represent males. White circles and squares indicate persons of normal intelligence, as far as records are known. Black circles and squares indicate feeble-minded individuals. How does this scientific study of a real family prove that feeble-mindedness is inherited?

***Mendel's laws and human inheritance.** The transmission of human qualities occurs according to the same principles that govern inheritance in lower animals and in plants. As is true with other living things, many aspects of human inheritance are not yet fully understood. But many facts of the greatest importance are definitely known. A good illustration is found in the inheritance of feeble-mindedness and of normal-mindedness (Fig. 412). Normal-mindedness is usually a dominant character, and feeble-mindedness is usually recessive. Children of a feeble-minded parent and of a normal parent who has no feeble-minded ancestry almost always appear normal in the first (F_1) generation. All such children, however, are really hybrids between these contrasted characters. When these hybrids later become the parents of a third generation, the feeble-mindedness is likely to appear.

Many other undesirable characters are associated with hereditary physical defects. It is now thought that criminality or the tendency to commit serious criminal acts, pauperism or the tendency to do nothing effective toward one's self-support, and immorality of various sorts may often have hereditary causes. In fact all these undesirable characters are somewhat related, and

FIG. 413. Six feeble-minded members of one family.[1] How would you explain the meaning of this picture to one who had not studied biology?

all are frequently found in the same family (Fig. 413). Still other undesirable traits which "run in families" and are therefore hereditary include epilepsy, some forms of insanity, hunchback, fingers lacking the normal number of bones, harelip, cleft palate, deaf-mutism, some forms of blindness and deafness, and certain weaknesses which make the individual liable to contract certain kinds of disease.

*But inheritance of physical defects is no more certain than is the inheritance of desirable traits. Many superior characters are known to be hereditary. There are records of families in which for several generations members have been noted for their achievements in science, literature, art, music, and other fields of worthy endeavor (Fig. 414). The mental and physical characters making such achievements possible are transmitted through the same laws that control inheritance of other qualities.

There are no pedigrees for human beings that compare in ac-

[1] From Caldwell, Skinner, and Tietz's *Biological Foundations of Education.*

curacy with those for farm animals. There is no doubt, however, that the improvement of future generations depends in a large

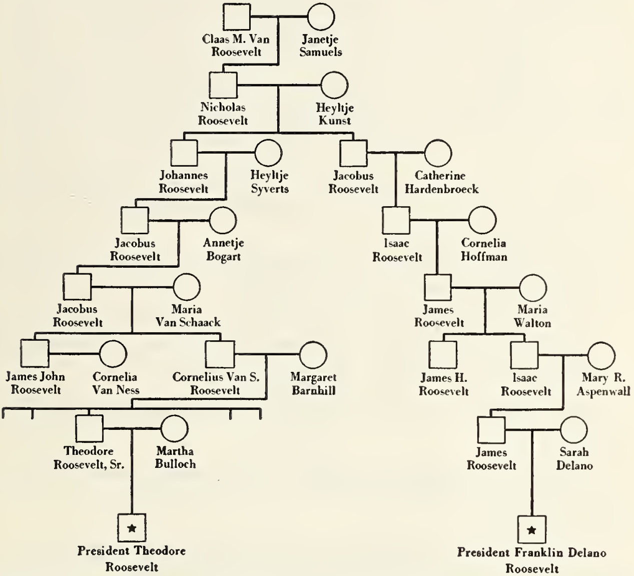


Fig. 414. The Roosevelt family shows the value of good heredity.[1] These people have all been desirable citizens, and some have been eminent. Special Report: Consult an encyclopedia for facts about the Jonathan Edwards family

measure upon selection of good human stock. In the absence of human pedigrees that tell whether undesirable traits existed in recent generations, people often marry other individuals who, though apparently normal, carry defects in their genes. As a result undesirable traits may appear in the children. Really intelligent human beings will be concerned to know the kind of human stock from which they are descended. They will want to make sure that, in so far as they are concerned, the succeeding generation shall have the best possible inheritance.

*Any individual person already possesses his own inherited

[1] Revised from chart by George A. Smith, Carnegie Institution of Washington.

qualities. Some of these qualities are of superior nature; some may possibly be undesirable. Even though one may recognize his own qualities, he cannot remake his own inheritance. But one can guide himself and select and adjust his surroundings or environment in such ways as to give his best qualities ample opportunity to develop, and to suppress his undesirable qualities. Indeed, one's strength and achievement depend largely upon the ways in which he makes the best uses of all his inherited qualities.

Self-test on Problem XXXI–D. **1.** The laws of inheritance established by the scientific experiments of *Mendel* have been used to produce superior plants and animals.

2. State the methods used by plant-breeders and animal-breeders in their attempts to produce improved varieties.

3. Name at least ten undesirable human traits which can be inherited.

4. Desirable human *traits,* as well as undesirable *ones,* can be inherited.

5. People are likely to have *only* good *or* bad traits.

6. One's *inheritance* can be changed; one's *environment* cannot be changed.

Exercises on Biological Principles. **1.** How many instances can you find to illustrate this statement: "New kinds of living things have arisen through mutations"?

2. Give one or more illustrations of these statements: "In plants and animals certain traits are usually dominant while others are recessive. In other instances neither trait is dominant, with the result that a hybrid offspring has characters intermediate between those of the parents."

3. How would you explain this statement to someone who had not studied heredity: "Living things reproduce offspring which possess the genes of their ancestors, though they do not necessarily resemble any one of these ancestors"?

4. Could this statement be true: "Pure-bred black mare mated with a pure-black stallion resulted in white colt"? Quote one of Mendel's laws in support of your answer.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. **1.** With hogs, white is dominant over black. If a white pig and a black pig are crossed, what will be the appearance of the F_1- generation offspring? Will they be pure-bred or hybrid? If two of these pigs of the F_1 generation are crossed, what will be the color of their offspring?

2. Using the facts given here, make up and solve problems similar to 1.

Plants or Animals	Dominant	Recessive
Cattle	Black	White
Cattle	Hornless	Horned
Guinea pigs	Black	White
Horses	Bay	Black or chestnut
Horses	Trotting	Pacing
Hogs	White	Black
Cats	Black	Blue
Cats	Hair short	Hair long
Dogs	Gray	Black
Dogs	Hair short	Hair long
Man	Skin and hair dark	Skin and hair light
Man	Eyes dark	Eyes blue
Man	Hair curly	Hair straight
Garden peas	Flowers colored	Flowers white
Garden peas	Stems tall	Stems short
Garden peas	Seeds smooth	Seeds wrinkled
Garden peas	Seeds yellow	Seeds green
Corn	Yellow	White

3. Suppose you have some dwarf poppies that bear beautiful red flowers; also, tall poppies with white flowers. If you want to produce a tall plant with red flowers that will breed true, how will you secure such a plant?

4. What does it mean to say that a characteristic "skips a generation"? Could it skip two or three generations? Explain.

5. Recently in a litter of kittens was one with an extra toe. The cat grew up and has since had a number of children and grandchildren with extra toes like itself. Is the cat a freak or a mutant? Explain.

6. How would one determine whether a unit character is dominant or recessive?

7. How could a child of brown-eyed parents have blue eyes?

8. Make a chart showing the inheritance of some characteristic in your family. Hair color, eye color, curly and straight hair, and such characters are sometimes striking illustrations.

9. Name a variety of plant or animal which did not exist one hundred years ago. How was it developed?

Project 25. To prepare illustrations of common variations. (1) By examination of the leaves of one tree or shrub select and fasten to sheets of paper samples of leaves that differ in any way from one another. How many variations can you find upon any one plant? (2) Examine a litter of kittens or of pups and prepare a chart listing or illustrating all the differences you can find among the individuals of such a litter.

Project 26. To produce hybrid plants by controlling pollination. Plant some field corn and some sweet corn in good soil in a garden or field. Just before the ear (pistillate) flowers and tassel (staminate) flowers open, tie paper bags over the ears so that no pollen may enter except that which is desired. When the stamens are ripe, carefully place pollen from each kind of plant upon the silk of the ears of the other plants and replace the paper bags for two weeks. Then remove the bags and allow the ears to mature. When they are mature, collect all the ears into two lots, remove the husks, and see how many of the grains show the qualities of each kind of parent plant.

Special Reports. 1. Find and present some additional facts about the work of Mendel.

2. Consult an encyclopedia for facts about the Kallikak family; the Jukes family; the Wedgwood-Darwin-Galton family.

3. Find evidence to support the statement "Most of our food plants and our domestic animals have been developed from less desirable wild varieties."

Questions for Debate. 1. *Resolved,* That the work of Edison has proved to be of greater practical value to the world than that of Burbank.

2. *Resolved,* That the government is justified in restricting immigration to those who are themselves at least normal and who can present a satisfactory pedigree for at least three generations back.

3. *Resolved,* That environment has more influence than heredity over what an organism finally becomes.

Chapter XXXII · The Records of the Ages

Questions this Chapter Answers

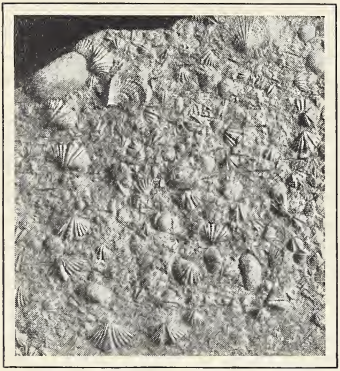
What are some of the ways in which the surface of the earth is slowly but constantly changing?
What are the various types of fossils and how were these formed?
What kinds of records are made in fossils?
What do coal and fossils tell us about the ancestors of modern plants?
What fossil evidences are there regarding modern animals?
How are recent and present life related to past and future life?

Problem XXXII–A · What Causes Scientists to Believe that Life now on the Earth is Descended from Ancient Life?

Change always occurring. If you examine the walls of a gravel pit or of a sand pit or of an excavation that is being made for construction work, you are likely to find evidence of ancient action by wind or water or both. The sand, gravel, and soil show clearly that they were deposited in layers. Even the larger rocks sometimes show that they were deposited by very strong water currents or by ocean waves. Moreover, along steep banks or on slopes of hills and mountains one may sometimes see places where great masses of earth have slid downward, sometimes a few feet, sometimes a mile or more. Such sliding masses carry everything with them: soil, rocks, plants of all kinds, even animals, and in rare cases the homes of men. In places where the soil is of sand or loam, strong dry winds sometimes carry away thousands of tons of the earth's surface and deposit it elsewhere.

The earth is always changing. What was a river bottom ages ago may have been filled and may now be part of a fertile field. When it was a river bed, logs, stones, and masses of gravel and sand may have been buried. When today we dig down into the old river bed, we may find the buried evidences of former life and may learn some of the facts about the times and conditions in which these things lived.

Records of plants and animals that used to be. Fossils of several kinds help to reveal the world's ancient past. Probably the most common are the shells of snails, clams, and other animals the bodies of which were protected by hard coverings (Fig. 415). Others are structures which have petrified,[1] bones which have not decayed, occasional animals and plants preserved in ice or in amber, and often such evidences as footprints or worm casts made in mud that later was changed to stone. By the study of fossil shells it is learned that they were the coverings of animals related to those that now live upon the earth. In general the older the beds in which the shells are found, the less is the resemblance of the shells to animals now living. This is not always true, however. In a few cases very old shells are found that closely resemble those of present-day forms. Such evidences show that animals now living are related to those of past ages.



A. M. N. H.

FIG. 415. Rock composed largely of fossil shells. What does the presence of these shells tell about the history of the rock?

Near Los Angeles there are famous pools of ancient tar or pitch. Animals which happened to get into these pools slowly sank into them. The flesh of the animals was destroyed, but the bones remained as authentic history of the animals which inhabited this region during many centuries (Fig. 416).

Most fossils, however, are found in beds of rock that have been deposited throughout long ages while water was carrying mud, sand, pebbles, and dead bodies of plants and animals into the deeper parts of the swamps, lakes, and oceans. It was in this way that these fossils were formed. Sometimes plants and animals were buried in soil which was moist with water in which minerals were dissolved. As the plant and animal bodies decayed, mineral

[1] *Petrify* (pet'ri fy): to replace plant or animal material with rock.

Los Angeles Museum of History, Science and Art

Fig. 416. How the California tar pits are supposed to have appeared. How did so many different animals, especially the flesh-eaters, happen to be caught in the tar?

matter from the water was deposited in their places. The stone as it was deposited in the tissues of the plant or animal took the form of their parts. In this way the petrified trees and the fossil "bones" of animals were formed. Sometimes the deposited minerals took the places of even the softer structures, thus preserving the entire bodies of plants and animals.

Such fossils make up very important parts of the chapters in nature's history of the long ages of the past. Those who learn to read fossils and the layers of rock in which they lie may read much of the world's ancient history, and by doing so may have a better understanding of life now upon the earth.

Coal, a record of past life. At different times in the past and at different places on the earth tremendous swampy areas were covered with most luxuriant vegetation (Fig. 417). Living among this vegetation were various kinds of small animals. These plants and animals lived before the time of the largest animals. Warmth and moisture caused the plants to grow rapidly. As the older ones fell upon the warm swampy surface, they slowly settled into it and were buried by water and the accumulating solid materials. Great masses of these fallen plants finally became buried beneath heavy layers of mud, sand, and rock. These plant materials were slowly turned to coal, probably partly through the action of bacteria and partly through heat and pressure. Sometimes the plant structures, such as branches, stems, or roots, kept their original forms even though they were changed to coal. Sometimes animal remains were likewise preserved in the plant layers. By a study of these plant and animal fossils it is possible to tell what the plants and the animal life were like during the coal-forming ages.

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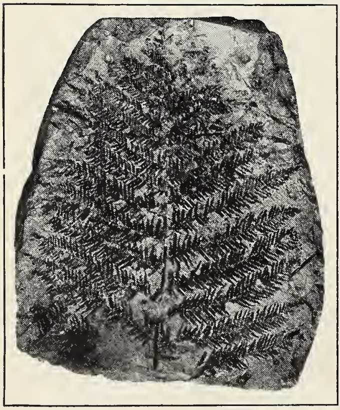
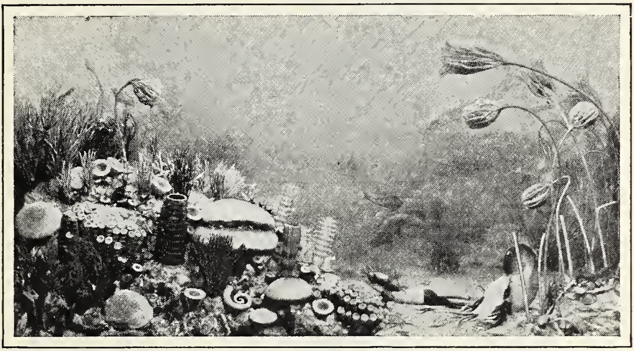
Fig. 417. How a coal-age forest is supposed to have appeared. Note the six-inch cockroaches on the trees and logs, and the huge dragon fly. Is it likely that coal is being formed in any part of the earth today? If so, under what conditions?

The ancestors of modern living things. As stated in Chapter IX, present-day ground pines, or club mosses, and the scouring rushes are the modern remnants of ancient plants which in coal-forming ages were small trees (Fig. 418). One of these fern ancestors has a name meaning "scale tree" (*Lepidodendron*), because the bark had heavy scales looking somewhat like the scales on an alligator's skin. The tree had no leaves like those seen in modern plants, but the scales served as leaves. The ancient relatives of the scouring rushes reached a height of not less than twenty feet, but in form and structure they closely resembled the modern scouring rushes. Ancient tree ferns, gigantic in size, were much



A. M. N. H.

Fig. 418. A fern print in coal. Which of the types of fossils does this represent?



Buffalo Museum of Science

FIG. 419. Some organisms which lived ages ago (Devonian age) where Buffalo, New York, now is. What evidence is here to support any of the principles cited below?

like the modern tree ferns which thrive in moist tropics. They reproduced their kind in ways quite similar to those of modern ferns.

*From the bits of evidence found in the fossils of various kinds, scientists have been able to piece together bit by bit much of the history of living things for several hundred million years (Fig. 419). There are still many omissions, which are more numerous and extend over longer periods as the study goes farther and farther into the past. Also much that is stated is still theory, because enough evidence has not yet been discovered to establish the truth completely. Yet there is so much evidence that competent scientists do not now question the truth of the following principles:

1. The earth is very old, probably at least a billion years and perhaps more than two billion years.
2. The surface of the earth is slowly but constantly changing as a result of natural laws and processes.
3. The earth was hundreds of millions of years old before life of any sort appeared upon it.
4. Plants lived on the earth ages before any animals appeared.
5. All the kinds of plants and animals now living are but a small part of the total number of kinds that have lived on the earth.
6. Things now living have developed from earlier living things.
7. In general, modern plants and animals are more complex than those of ancient times.

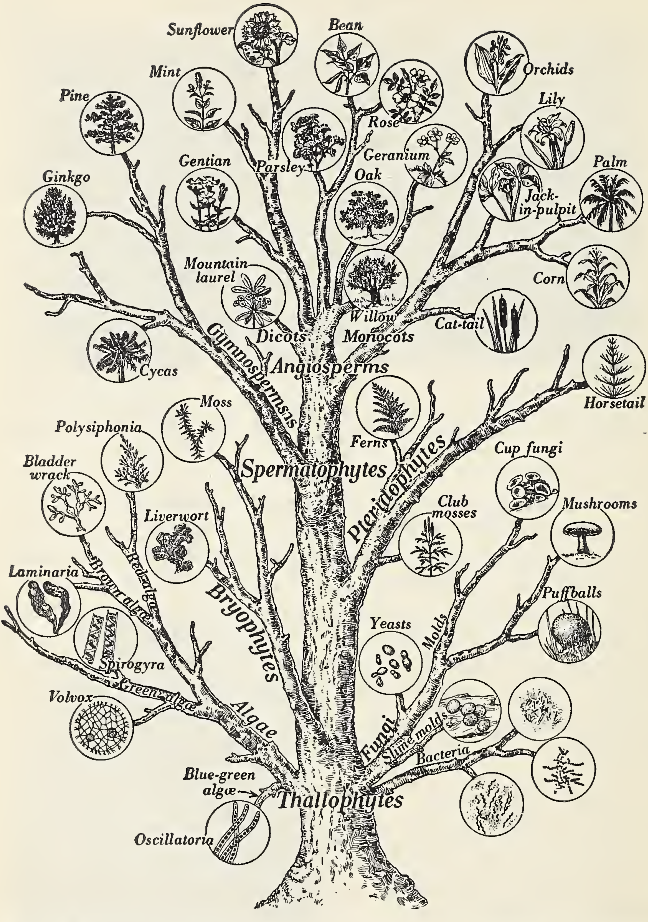


FIG. 420. Diagram showing how plants are related.[1] The undiscovered common ancestor of two or more known forms is sometimes called a "missing link." Can you explain this term?

[1] After Gruenberg's *Biology and Human Life.*

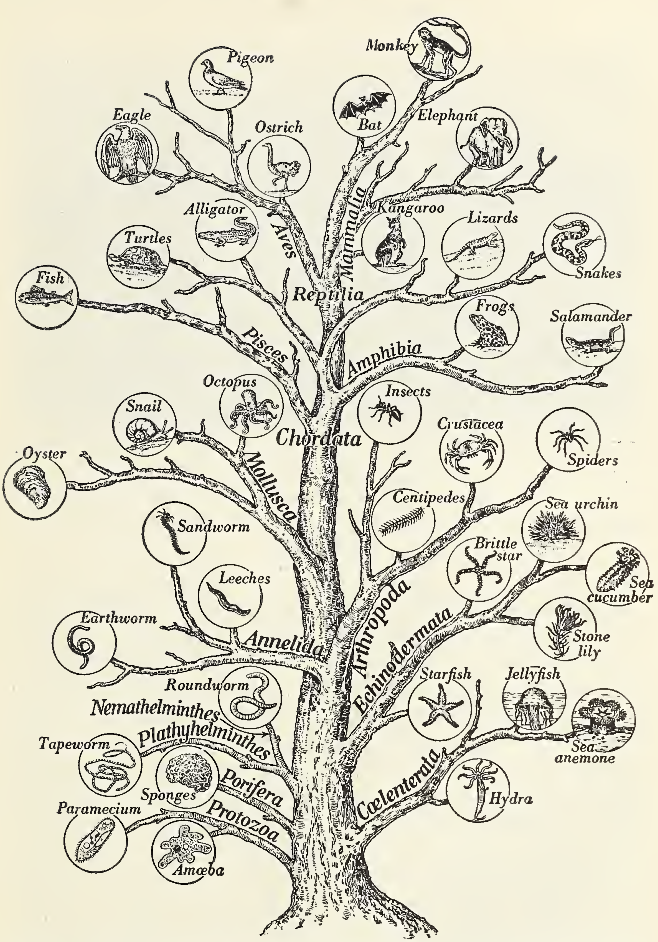


Fig. 421. Diagram showing how animals are related.[1] The volvox is here put on the plant tree. Some biologists place it on the animal tree. How do you account for this difference in classification?

[1] After Gruenberg's *Biology and Human Life.*

U. S. National Museum

FIG. 422. Digging fossils at Two-Medicine, Montana. The white objects are bones which have been wrapped in burlap and plaster. The dark objects on either side of the nearer white ones are uncovered bones. What values are derived from such studies?

Living evidences of ancestry. There is much evidence besides that found in a study of fossils to show that present living things descended from those of earlier times. There are the facts (1) that the embryos of the different kinds of higher animals appear so much alike (see Fig. 382, p. 589); (2) that the higher animals have corresponding parts, such as head, arms, legs, feet, heart, lungs, digestive system, and so on; (3) that the higher animals have certain structures which, though poorly developed, correspond to similar well-developed structures in lower animals. Such structures include the vermiform appendix in man; the third eyelid (nictitating membrane, as of the frog); gill openings, which in the higher animals appear only in the embryo stage but which in the lower animals are well developed and useful in the completely developed individuals; the pineal gland, which corresponds to a "third eye," which was useful in certain lowly, ancient, mud-burrowing fishes.

The evidences secured from various scientific fields have made it possible for scientists to find the relationships of the organisms

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FIG. 423. Millions of years ago this hairy elephant was common in many parts of North America. How many reasons can you suggest which might explain why it has become extinct?

now living not only with each other but also with those which once lived but long since became extinct (Figs. 420 and 421).

Living things then, now, and to be. Science in its tireless search for truth is constantly throwing a clearer light upon the procession of living things through the ages (Fig. 422). Each year adds to what is known of animals and plants of the past (Fig. 423). Each year adds to what is known of the relation of past life to that now upon the earth. The plants and animals now living take on added significance when we consider them as the present representatives of long ages of development of life upon the earth (Fig. 424). Those now living, like us ourselves, are merely the individuals of nature's procession of life through which past life and future life are connected. We may change a few kinds of plants and animals, through breeding or cultivation, to fit our wishes. Change follows change through succeeding ages until finally there may be forms very different from those now seen. Or climatic conditions may change so as to affect some kinds of life that are now abundant. These may be at first confined to areas where conditions for a time permit them to live; then finally they may disappear from the earth. Such occurrences have doubtless been frequent through the age-old development of plants and animals upon the earth. Those

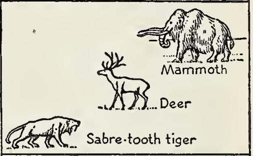
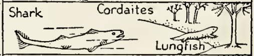
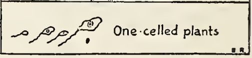
Per Cent of Total Time	Era	Age	Geological Period	Dominant Types of Life
0.2	Psychozoic	Age of Man	Recent	 Man
	Cenozoic	Age of Mammals	Pleistocene	 Mammoth; Deer; Sabre-tooth tiger
1.9			Pliocene	
			Miocene	
1.9			Oligocene	 Eohippus; Rhinoceros
	At least twenty million years ago		Eocene	
5.0		Age of Reptiles	Cretaceous	 Bird; Marsupial; Tyranno-saur; Flowers
3.75	Mesozoic		Jurassic	 Pterodactyl; Diplodocus
2.25	At least seventy-five million years ago		Triassic	 Dinosaur; Mammal
3.0		Age of Amphibians	Permian	 Dragonfly; Calamites; Stegoce-phalean
6.0			Pennsylvanian	
			Mississippian	 Crinoid; Brachiopod
4.5	Paleozoic	Age of Fishes	Devonian	 Shark; Cordaites; Lungfish
3.0			Silurian	 Scorpion
7.5			Ordovician	 Armored fish
6.0	At least two hundred and twenty-five million years ago		Cambrian	 Trilobite; Orthocerid
25.0	Pre-Cambrian	Age of Invertebrates	Proterozoic	 Sponges
30.0	At least five hundred million years ago		Archeozoic	 One-celled plants

FIG. 424. Can you explain this chart, constructed from a study of fossils?

who study biology some thousands of years hence will find a different biology to study. But its principles and its processes are likely to be continuous with those you have studied and upon which you have made a mere beginning.

Self-test on Problem XXXII–A. **1.** Name at least four different types of fossils.

2. In general the deeper a fossil is buried, the more *ancient* it is.

3. A petrified plant or animal is *always* the body of the plant or animal which has been changed to stone.

4. *Large* animals and plants were on the earth long before *small* animals and plants.

5. *No* forms of life now on the earth are larger than the ancient animals.

6. State some of the evidences which lead scientists to believe that present living things are descended from ancient living things.

7. *Animal* life is believed by scientists to have been on the earth before *plant* life.

Self-test on Biological Principles. **1.** State evidence from the chapter which will support each of the principles found on page 643.

2. What evidence can you cite from any portion of the book which will seem to add proof to the following principles?

1. From lower to higher forms of life there is an increasing complexity of structure, and this is accompanied by an increasing division of labor.

2. The energy which makes possible the activity of most living things came at first from the sun and was secured by the organism by the oxidation of food within its body.

3. Species not fitted to the conditions about them will not thrive and finally will become extinct.

4. Certain associations of plants and animals are the result of a struggle for survival — for example, community or social life, parasitism, and symbiosis.

5. There is hardly a region on the earth's surface where some form of life does not exist.

6. Life exists from the depths of the ocean to the mountain heights.

7. Life may exist under conditions of light ranging from bright sunlight to the darkness of caves.

8. Living things have become adapted to wide ranges of physical conditions.

9. Plants and animals are directly or indirectly dependent upon the soil.

10. Green plants depend on nongreen plants for certain materials necessary in food-building.

11. Man has modified plant and animal forms through knowledge of biological principles.

12. Living things may exist under conditions of temperature ranging from many degrees below 0° C. to nearly the boiling point of water.

13. All living creatures have living enemies which compete with them for available energy.

14. Living things resemble their parents in general, but vary from them in some respects.

15. Plants and animals are dependent upon one another in various ways.

16. All living things carry on the same necessary life processes, such as nutrition, respiration, excretion, sensitivity, and movement.

17. The work of chlorophyll is essential to all living things.

18. Reproduction is essential if life is to continue upon the earth.

19. Changes in physical surroundings are accompanied by changes in living things.

20. The more highly specialized an organism is, the more likely it is to become extinct if its environment changes.

ADDITIONAL EXERCISES AND ACTIVITIES

Problems. 1. Do you know of places which prove that conditions used to exist that are different from those of the present? Give your evidence.

2. Under what conditions could fossils be forming today?

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Unit IX · *Biology for Leisure Time*

The preceding eight units of this book have presented the materials necessary to give a knowledge of the nature of biology, its facts, its laws and principles, its importance and values. You may now have gained a biological background which you can use in studying and understanding life wherever you find it. It is worth while now to give more attention to the question of how to use your biological knowledge for further pleasure and for recreation.

This chapter describes a large number of biological pastimes, hobbies, and recreational activities. It is not intended to be studied as you have studied the preceding ones. It is intended to serve as a source to which you may turn often for ideas and directions for making the most of leisure hours. These activities described are similar in nature to the experiments, projects, and activities scattered throughout the first eight units. Those, however, were mostly intended to be carried on in school, either in the classroom and the laboratory or in the science club. The activities described here are intended to serve for recreation during the out-of-school hours both out of doors and indoors.

Chapter XXXIII · Biology for Leisure Time

Problem XXXIII–A · How can Biological Knowledge be Used in Out-of-Door Pastimes?

Field trips and things to do. Field trips may be for the purpose of observing and identifying plants and animals or of collecting (Fig. 425). Suppose you are going out for the purpose of observing insects. Do not rush along, or you will miss the most interesting and worth-while sights. Stop for half an hour beside an ant hill. What do you discover about ants that you never knew before? Look in the sand a few feet away from the ant hill for a cone-shaped hollow about four inches across. Something moves at the bottom. An ant, hurrying along, suddenly finds itself sliding down the steep slopes of the hollow. It frantically tries to scramble out, but the loose sand lets it slip farther and farther down. Quickly a pair of jaws reach up from the bottom of the pit and seize the struggling ant. Thus you are introduced to the ant-lion larva, or doodle bug, the builder of the pitted trap. Use a stick to take the ant lion out of its home. Place it on the sand and watch it build another trap.

Ruth Alexander Nichols

Fig. 425. Off for a nature trip. What equipment would they need for insect-collecting? [1]

When you go out on a trip to identify plants, take along a book which contains a key and perhaps pictures and descriptions to help you to identify the various kinds you find. Try to learn how to name and recognize common weeds, trees, and spring, summer, and autumn flowers. Even during the winter you can study the conifers and no end of seed pods of flowering plants.

[1] Courtesy, Girl Scouts, Inc. and *Health and Physical Education.*

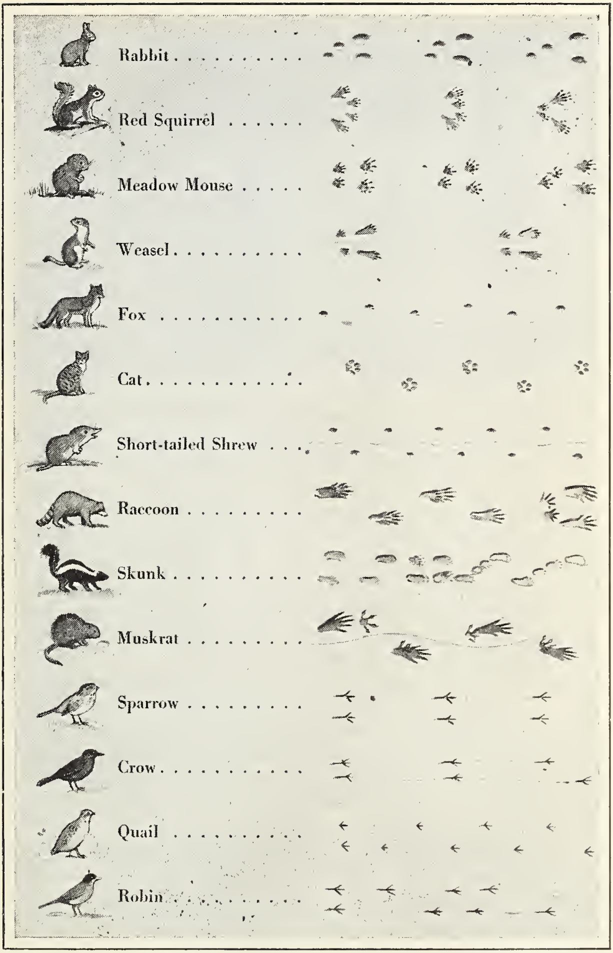


FIG. 426. Animal tracks. How do you account for the differences in the sizes, shapes, and positions of these various footprints?

Fig. 427. If you were mounting these pictures in your biology photograph album, what comments might you make concerning them? For example, what might you infer concerning the nature of the bird from the type of nest it built?

Field trips may be useful at any season of the year. People are likely to think that there is nothing to interest the biologist out of doors in the winter. But if you take a field trip on any mild winter day, you will be surprised at the evidences of life you can find. Have you ever tried examining the tracks in the snow to see what animals have gone before you (Fig. 426)? Can you recognize such common tracks as those of the crow, the rabbit, or the meadow mouse?

Try making plaster casts of bird and animal tracks found in moist sand or mud. You should not mix the plaster until you are ready to use it. Pour plaster of Paris into a little water and stir it with a stick or a spoon. Make the mixture thin enough so that it will pour readily. Pour it into the track, and leave it until it is well set. Remove the cast by digging carefully around it. When it is very hard and dry, you can scrape off the mud and wash the cast clean.

Look for examples of special adaptations to the environment, such as protective coloration, types of leaves suitable to the amount of sunshine, tall or flat plants, and so on. Also look for examples of unsuccessful struggles for existence. Try to find out in each case why the struggle was unsuccessful. A dead tree in a dense thicket would furnish an example of unsuccessful struggle. Look for examples of successful struggles under difficult conditions, for example, a sturdy robin with a broken leg.

Keep a diary in which you record your outdoor observations and adventures.

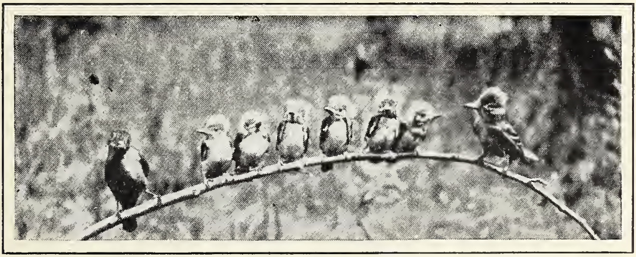


FIG. 428. A family portrait. The young flycatchers were carefully lifted from the nest to the twig, where they were joined by the mother and father birds. After the picture had been taken, the young birds were carefully returned to the nest.[1] To what birds are the flycatchers related? (Consult a bird guide)

Photography. It is not necessary to have an expensive camera to get good nature pictures. An ordinary small camera will give surprisingly good results if proper care is used. If your first pictures are not very satisfactory and if you have not been able to find where you made mistakes, ask a photographer to make suggestions for improvement.

Try pictures of plants first. They will not run away just as you get them in focus, nor move just as you snap the shutter, though the wind may move the leaves and twigs. Such pictures as the following may be very beautiful if you will take time to get them right: (1) trees in winter outlined against the sky; (2) trees in full leaf to show typical shape and branching; (3) trees or bushes loaded with snow or sleet (Fig. 427, *A*); (4) flowers, especially if you take these at the shortest possible distance which will give a clear picture.

Animals are often hard to photograph with an ordinary camera under usual conditions. You may with luck get close enough to a deer or other large animal to get a good picture. You can climb into trees for pictures of nests (Fig. 427, *B*) and of young birds. But as a rule you cannot get close enough to photograph a bird or a small animal with an ordinary lens. For such pictures a special lens attachment for distance is needed.

In some of the nature books or in magazines such as *Nature Magazine* look for articles describing how animals can be made to take their own pictures. Sometimes a wire across the path is adjusted so that when the animal touches the wire a flashlight explodes and the camera shutter clicks at the same instant. Sometimes the string or the wire that takes the picture is attached to food. Perhaps you can persuade the animals to pose for you by providing food or by some other means (Fig. 428).

[1] From a photograph by H. T. Middleton. Courtesy of the *Nature Magazine.*

Bird studies. 1. *Field work.* One of the most interesting field trips is the "bird hike." The best time to go is in the early morning, just about sunrise; for then the birds will be busily hunting their breakfasts. During the warmer part of the day they are usually more quiet and in the shade. If you cannot go in the morning, the early evening is a fairly good time for observations.

Take along a small notebook for keeping records, also a bird guide (see book list, p. 675), that is, a book which gives descriptions and pictures of birds. A pair of field glasses will be of help in observing the birds, but is not absolutely necessary. You can soon learn to identify many birds by their plumage. It is interesting to note, too, that you can often distinguish a bird by its manner of flight. The goldfinch, for example, flies in a peculiar series of rolling darts. The quail moves its wings rapidly for a few beats, then glides. The robin moves its wings almost continuously. The chart on the opposite page lists some of the more common birds and indicates some facts which one should learn about them.

Consult a bird book to learn the color markings of these birds. When you have learned to recognize the birds, copy the chart and try to complete it from your own observations in the same manner as that indicated for the bluebird. (Do not write in the book.)

Since one can often hear a bird when it cannot be seen, it is most desirable to learn some of the songs and calls. The easiest and surest way to do this is to go out with someone who knows birdcalls. You can learn much by yourself, however, by following a sound until you see the bird and by then memorizing the notes or by making a record of them in your field book.

If you would see and hear birds, be quiet in the woods. It is better to go on bird trips in very small groups. There will then be less talking and disturbance. Sit quietly in one spot for a while. Many birds which you otherwise might never see will come close to you.

It is always with a thrill that one sees the first robin or the first bluebird of the season. Many people like to make a bird calendar on which is recorded the dates on which each kind of bird was first observed during the year.

We rarely suspect how many kinds of birds remain with us during the winter until we start feeding them. Scatter bread, wheat, ground corn, pieces of fat meat, and other kinds of food on the ground, or tie food to the trees, or place it in boxes in the trees. Keep a record of the birds which come for food. Do the same ones come day after day? Are there some kinds that seem easily frightened away? If so, can you devise other methods of feeding them?

If there is someone in your school or neighborhood who is conducting bird-banding experiments for the Biological Survey, you may secure per-

Name	Size	Color Markings	Habitat	Season when Observed	Kind of Food	Location of Nest
Bluebird	Slightly smaller than a robin	Bright blue with orange breast	Open ground near houses	Summer	Insects	In holes in tree trunks
Catbird						
Crow						
Chickadee						
Baltimore oriole						
Robin						
English sparrow						
Downy woodpecker						
Barn swallow						
Flicker						
Goldfinch						
Phœbe						
Herring gull						
Screech owl						
Song sparrow						
Yellow warbler						

mission to help. You will have to devise a trap in connection with your feeding station, but of course will have to make sure not to injure or frighten the birds. It is most interesting to keep a record of the number of times the same banded bird will go into the trap. It is thrilling to discover in your trap a bird which was banded the previous year and which after its long migration has come back to the same yard.

2. *Bird houses.* Forty-five species of birds are known to nest in bird houses. But of course just any kind of house will not do. You have to put up the kind that will be attractive to the species of bird you want. You can secure from the United States Department of Agriculture a valuable bulletin giving directions for making bird houses of many kinds. If you build your bird house in the autumn, and put it out to weather through the winter, the birds will like it better than they will a very new one.

3. *Observation of nesting habits.* One of the most valuable studies is to make a detailed observation of the nesting habits of a pair of birds. You must make your study in such a way that the birds are not disturbed or frightened away. A good rule is to be quiet and make no quick or disturbing movements. Secure as much information as you can on as many of the following points as possible:

a. The building of the nest. What kind of location is chosen? What kinds of material are used? How long does it take the birds to build the nest? Do both birds work at it?

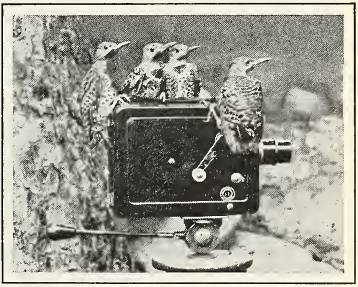
b. The eggs. How soon after the nest is completed is the first egg laid? Record in your notes the dates on which other eggs are laid. Describe the eggs as to size, color, and markings. How many eggs are laid? Does the female start incubating as soon as the first egg is laid, or does she wait until all have been laid? Does the male sit on the nest part of the time? How long at a time are the eggs left uncovered while both parents are out hunting food? How many times a day? At what hours?

c. The young. How many days are required for incubation? Do all the young hatch on the same day? What is their appearance? Keep careful notes on their development. How fast do they grow? When do the feathers begin to appear? What do the parents feed the young? How do they feed them? How often? Do both parents help in getting food? How old are the young birds when they first seem afraid of you? When are the young ready to leave the nest? Describe their actions as they are learning to fly and to get food for themselves.

Your record may be illustrated by photographs (Fig. 429). It is easy to get close enough to the nest and the young to get good pictures even with a small camera. Be very sure not to disturb the nest or to frighten the parent birds. Otherwise they may abandon the nest and the young.

Making collections. Most young people and many older ones enjoy hunting for and collecting things. You can make many kinds of collec-

tions of biological materials which will be both valuable and interesting. Here are a few suggestions. You will find others in other parts of this chapter. You will think of still others which do not appear in this book.



Lynwood M. Chace

Fig. 429. Hunting young flickers with a camera. "They watched me with greatest curiosity and stared with wide-open eyes at my maneuvers." Where are these birds likely to be found?

Sometimes one goes out on a collecting trip with the particular purpose of looking for one kind of plant or animal. But on many trips one can, if he is prepared, secure an unusual specimen which otherwise he might miss. It is well, therefore, to put into your pocket some kind of container that will protect your material until you get home. Such equipment might include some folded newspapers or paper sacks for plants, one or two bottles for live material, or an insect-killing bottle. You will thus be able to collect many different kinds of interesting specimens you would otherwise be unable to keep.

A biological collection is not merely a pile of material. It is a group of objects which bear some sort of relationship. Thus you may make a collection of living materials for an aquarium or a collection of tree leaves or of insects. Or you may select some smaller and definite part of one of the larger groups, as a collection of butterflies or of oak leaves. Another collection may relate to habitat or to habits rather than kind, as a collection of the life found in a pond, or of the insects that feed on shade trees, or of the seeds that are carried by the wind. Still another collection may contain only one species of plant or animal, as a collection of the stages in the life history of a butterfly.

The suggestions which follow are intended to help you to collect and to care for your material most effectively.

1. *Pond life.* From a pond or small lake you can collect many interesting water forms which will live well in an aquarium (Fig. 430). You can secure many of them with your hands or by dipping with a pan or jar. For others you will need some sort of net or a wire strainer. Quart fruit jars make good collecting bottles. Do not put too many animals in one jar. You should find snails, crayfish, and perhaps mussels in the water. Along the shore you may find frogs, toads, or salamanders. Insects will probably be abundant. Water boatmen, water striders, diving beetles,

Fig. 430. Collecting water life. What kinds of animals should you expect to find in such a habitat?

water scorpions, and back swimmers are among the common ones likely to be on the surface. Then look on the bottom for the larvæ of dragon flies, May flies, midges, and caddis worms.

When you return to the laboratory put the animals in an aquarium where they will have room enough. Be sure to have water plants where some of the smaller animals can hide from their enemies. Watch the aquarium closely for a while to see which ones seem inclined to eat everything else. These you may have to put in some other place. Put a screen over the aquarium, so that the insects which live on the surface will not jump or fly out.

Many kinds of water animals will live together in an aquarium. They require little care and make interesting pets. If you do not have a regular aquarium tank, use any sort of container that seems suitable. It should be wider than it is deep, to expose a large surface to the air. Square glass battery jars make good small aquaria.

It is best to fill the aquarium with water from a pond or a stream. If it is difficult to get this, perhaps you can get distilled water. If you have to use water from the city water supply, let the tank stand for three or four days after filling it, before you put in any plants or animals. On the bottom of the aquarium put an inch of sand which has been cleaned by thorough washing to remove all dirt. Then plant the water plants. Until they get well rooted, it is well to tie a stone to the bottom of the plant to weight it down. Do not use too many plants. If you can collect the plants yourself, go to any pond or small lake or to a quiet bend in a stream and choose some of the smaller plants which grow there. A little

Cornelia Clarke

FIG. 431. Cases of the caddis-fly larvæ. What other insect larvæ which live under water would you be likely to find?

experimenting with different kinds will tell you which grow best and look best in your aquarium. If you buy plants from a florist, get one bunch each of such plants as *Vallisneria*, *Elodea*, and *Myriophyllum*, or perhaps *Cabomba* or *Ludwigia*, or others he may suggest. Let the aquarium stand for one or two days before you put any animals into it. This gives the plants a chance to start growing and gives you an opportunity to make any changes that seem best.

Do not crowd the aquarium. One three-inch fish to each gallon of water is enough. There is a large variety of fish to choose from: goldfish, or tropical fishes; or, if you can collect them yourself, minnows, bluegills, or others of our native fishes. Put in some animals which will help to keep the aquarium clean, such as snails, tadpoles, and a clam or a mussel.

An aquarium should not stand in bright sunlight for many hours at a time. It should, however, be placed where there is plenty of room light. At times algæ may grow on the sides of the tank or in the water in such abundance that one cannot see through the water. These algæ do no harm, but they affect the beauty of the aquarium. Usually one can scrape the glass clean with a razor blade without removing the animals or the water from the tank.

Caddis-fly larvæ may be collected in almost any pond or stream where the current is not too swift. Look for them on the bottom, crawling about or clinging to weeds and sticks. Those which live on sandy bottoms have houses built of pebbles (Fig. 431). Other kinds make their homes of bits of sticks or weed stalks cemented together. Gently remove a larva from its case and place it in a dish where there are bits of material from which it can make another home. Then watch it at work. If, instead of the tiny bits of sand or seed stems, you put fine pieces of mica into the water, the caddis worm may use these to make its house. You will then be able to observe the living worm through this transparent case.

2. *Cocoons.* After the leaves have fallen one can usually find many cocoons. Collect as many different kinds as you can. Put them in a cool place for the winter, or keep them out of doors. If you want the moths

to come out very early, you may keep them inside the home or the schoolroom. In that case do not let the cocoons become too dry. Put a moist sponge in the box with them, but do not allow it to touch them. In February or March put them in an insect cage, so that the moths will not escape when they emerge. If you have never watched a moth emerge from its cocoon and spread and dry its wings, you have a thrill to look forward to. Those which come out so early had best be added to your collection, for they could not find food outside. Directions for killing and mounting them are given in another part of this chapter. Do not destroy the cocoon from which the moth emerged, but mount it with the moth.

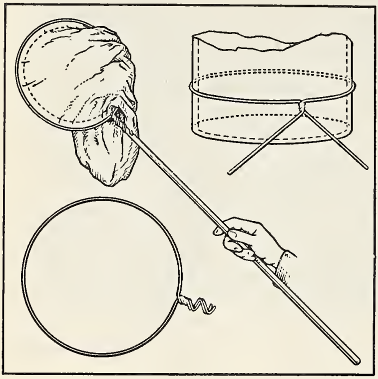


Fig. 432. How to make an insect net. What other equipment would be necessary for insect-collecting?

3. *Insects.* Insects may be found almost anywhere in such great numbers and of so many species that collecting them is always interesting. You will need a net to secure most of them. You will also need some sort of killing bottle. Make the net by bending a stiff wire to form a circle about twelve inches in diameter (Fig. 432). Fasten it to a broom handle or other stiff pole at least three feet long. To the wire attach a deep bag made of mosquito netting or marquisette or any material that is light yet strong enough so that the insects cannot push out through the meshes. For a killing bottle use any wide-mouthed jar with a tight cover. A mayonnaise jar or peanut-butter jar is quite satisfactory. Put in the bottom of the jar a piece of cotton soaked in gasoline, chloroform, carbon tetrachloride, or cleaning fluid. Over it put paper which will keep the insects from becoming wet. Do not, however, pack the paper so tightly that the fumes cannot come up into the jar. Fill the upper part of the jar loosely with torn strips of paper, to keep the insects from packing together and to absorb moisture that would ruin some of the specimens. Keep a separate jar for butterflies and moths. Indeed, large specimens of these insects should not be put into a jar at all. When you have one in your net, hold the net so that the insect will go into one corner. Then grasp the wings gently between thumb and finger and pour on the thorax

and abdomen a little gasoline or other killing fluid from a small bottle or an oil can. When the insect is dead, place it carefully in a piece of paper folded to make an envelope. Cut in the cover of a cardboard box a slit a little larger than the size of the insect's body. With your fingers or with fine forceps carefully spread the wings fully on both sides. Place a narrow strip of paper across the wings on each side and parallel with the body. Pin the paper firmly to the cardboard, placing the pins near but not through the wings. After three days your specimen will be ready for permanent mounting.

A cigar box or other box which will close tightly makes a good container in which to keep the insects permanently. In the bottom put a piece of linoleum, cork board, or corrugated paper into which to stick the pins. Use either common pins or insect pins. Stick the pins through the thorax of most insects. Make small labels giving the name of the insect, the date and place where it was collected, and any other essential information. Place these labels on the pin below the insect.

Butterflies and other insects with large wings are likely to be ruined if pinned in a box with other specimens. Secure a shallow box of any dimensions which seem suitable to the number of insects you wish to mount together. Cut a piece of cotton batting to fit the box. On this place the insects, with the proper labels. Make a cover by putting a piece of glass or cellophane in the lid of the box.

4. *Tree leaves.* Most of our common trees may be readily identified by their leaves. Take an old magazine along when you go leaf-collecting. As you put a plant leaf between two leaves of the magazine, write on the margin any items which will help you to identify the tree, as height, size, shape, appearance of the bark, kind of fruit. When you get home, put the leaves between newspapers. Place weights, as bricks, irons, or books, on the pile, and leave it for days until the leaves have dried.

There are many attractive ways in which you can mount the leaves. A separate sheet for each leaf is perhaps easiest to handle and to keep. Use firm enough paper so that the leaves will not readily tear off if the paper bends. Fasten the leaves with small strips of gummed paper placed over the stem and the tip of the leaf, or glue the leaf to the paper.

5. *Weeds.* Collect and dry whole plants in the same way as that described above for leaves. Many weeds are so large that it is not practical to use the whole plant. In that case take a portion of the stem and leaves that seems representative of the plant. When the part is dry, mount it with small strips of gummed paper, or cover it with cellophane.

6. *Flowers.* Do not pick flowers which are rare or which occur only three or four in a place. You can learn to recognize them as they grow, without helping to decrease their numbers. You might try taking pictures of them.

FIG. 433. The spore print (left) was made from this mushroom (*Amanita*). Is this mushroom edible? (Consult a mushroom book)

Collect and press flowers in the same way as leaves. If you press the flowers between sheets of waxed paper, they will keep their natural colors better.

7. *Seeds.* Make collections of weed seeds (1) that are carried by the wind or (2) that have hooks and spines which attach them to animals. Can you think of other interesting types of seed collections you might make?

8. *Fungi.* Fungi, such as mushrooms and bracket fungi, are found most readily in the spring or the autumn. The woody forms will dry and keep very well. But the fleshy-cap mushrooms are difficult to preserve. Put some of them in 70 per cent alcohol or 2 per cent formalin solution. Very interesting spore prints can be made of many of the cap forms. Cut off the ripe cap and lay it on a piece of white paper. Cover it with a glass or bowl to keep out air currents. Let it stand for a day until the spores have been shed. When you remove the cap, you will have a spore print showing clearly both the arrangement of the gills on which the spores were borne and the color of the spores (Fig. 433). If you want to make your spore print permanent, coat it lightly with clear shellac.

9. *Galls.* Galls are found on cedars, willows, oaks, roses, goldenrod, blackberry, and many other plants. The gall is a growth of plant tissue usually resulting when an insect lays its eggs within the plant or when fungi grow within it. Galls may be made by tiny wasps of several kinds, by certain flies, by beetles, or by plant lice. Occasionally they are caused by roundworms. An interesting collection may be made of all the kinds you can find. Classify them according to shape and general appearance.

10. *Twigs and buds.* These are especially suitable for winter collection. After a little practice you can identify trees by the character of their buds

and twigs. Dip the twigs in shellac or in wax to keep them from drying out. Then mount them on a heavy piece of cardboard or on wood.

Making leaf prints. Leaf collections may be unsatisfactory and hard to keep, because the leaves dry and crumble or become loose from their fastenings. You may therefore like to try some other methods of preserving leaf records.

1. *Ink prints.* You will need these materials: printer's ink, a plate of glass or other smooth surface, two rubber-covered rollers, and some paper. Put a small amount of the ink on the glass plate, and use one of the rollers to spread it evenly over a surface about the size of the leaf you wish to print. Place a leaf on the inked plate and run the roller over it several times until it is well covered with ink. Then pick the leaf up by the stem and lay it carefully on a clean paper. Cover it with another paper, and run the clean roller over it once. Any more rolling will blur the veining on the print. Remove the leaf from between the papers. You now have prints of both the upper surface and the under surface of the leaf.

2. *Smoke prints.* The materials you will need are a tin pan, some paraffin, and a candle or a kerosene lamp. If you have a rubber-covered roller, you can use it too. Heat the pan, and rub the bottom with paraffin. Then hold it above the lighted candle or lamp until it is evenly covered with smoke. Put the pan, smoked side up, before you, and lay on it the leaf you wish to print. Put a paper over the leaf and press the leaf firmly into the smoke. Remove the leaf and lay it on a clean piece of paper. Put another paper over the leaf, and smooth it once firmly with your hand or with the roller. Remove the top paper and the leaf. A smoke print does not last very well. If you want to make it more permanent, brush it lightly with a thin mixture of clear shellac.

3. *Blue prints.* Blue prints do not show the detail of leaf structure as smoke prints do. Yet they form very accurate and interesting pictures. Take a piece of blue-print paper somewhat larger than the leaf. Tack it to a board so that it cannot curl. Then place the leaf on the paper, weighting it with pebbles or bits of lead. Let it stand in the sunlight until the paper has faded to a very light shade. Then remove the leaf, take the paper from the board, and place it in water. Either put it in running water or change the water several times. When the leaf print is nearly white, remove the paper and put it face down on a piece of glass to dry.

Make an outdoor garden. Even though you may not have room for a vegetable or flower garden, you probably could find space for a small water garden or a rock garden.

Practically everyone enjoys a water garden. Nor is it difficult to plant one and to maintain it. Try, for instance, a tub garden (Fig. 434). A wooden tub of the kind in which certain kinds of supplies are packed, an old galvanized washtub, or a barrel with the top cut off will serve very

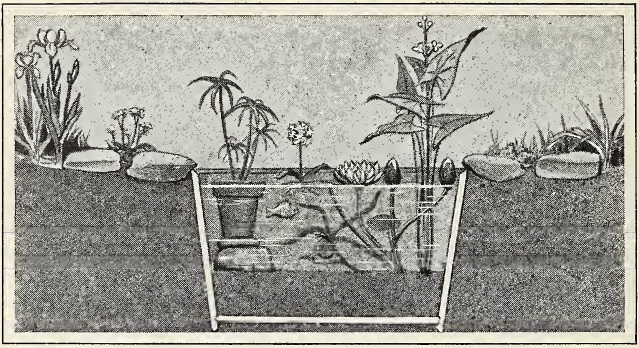


FIG. 434. A tub garden. The water garden should have a few animals—two or three fish, some snails, and perhaps a few tadpoles. Why?

well. If you have a garden or a yard in which you can find a good sunny place for the tub, dig a hole and sink the tub so that the top is just above the surface of the ground. Make an attractive border of rocks and small plants around it. Fill the tub about half full of good dirt, and fill the rest with water. Then plant the garden. In such a small pool probably one water lily, one water hyacinth, one arrowhead (*Sagittaria*), and some of the under-water plants suggested for the aquarium are enough. Now cover the soil with a layer of sand to keep the dirt from dissolving into the water and making it cloudy.

You can make a more permanent pool of concrete. It should be about one and one-half or two feet deep and of any other dimensions you wish. The way to plant such a pool is the same as that for the tub garden. As a rule, one need not remove the plants and animals from the pool in the winter. If plenty of water is kept in the pool and if it is covered with boards and leaves or straw, it will usually freeze very little. Keep the ice broken so that the fish can get air. Of course, if you have used plants that are not hardy, they will have to be taken up during cold weather. You would do well to ask the florist from whom you bought the plants whether you may safely leave them outside during the winter.

Rock gardens require very little space, though they can of course be large. Use small rocks, not more than half a foot square, as a rule. Fill the crevices with good soil. If the garden is in a shady place where the soil is moist and rich, you can have ferns and many kinds of flowering plants, as violets and columbine. If it is in a sunny place, use the typical rock-garden plants, like *Sedum* (stonecrop) and *Portulaca.* A florist will

help you to make selections; or if you go collecting for yourself, select those plants which grow naturally in the kind of place to which you wish to transplant them.

Problem XXXIII–B · How can Biological Knowledge be Used in Indoor Pastimes?

A scrapbook. A scrapbook will enable you to collect all sorts of interesting and up-to-date material to use in connection with your biology class or for a biology club. Plan to make the scrapbook rather large, perhaps nine inches by twelve inches or even twice that size. It will accommodate better the pictures you are likely to find in Sunday papers or in magazines. The rotogravure section is usually a source for fine pictures. Old magazines may contain pictures or articles of worth. Watch newspaper columns for such items as recent discoveries in disease prevention or in other fields of biology, biographical notes on living scientists, descriptions of habits of plants and animals, and similar interesting material that is not to be found in books. You may include in your scrapbook original drawings or sketches, cartoons, posters, or stories dealing with biology.

Posters or charts. Posters or wall charts make excellent exhibits to have in the classroom. They also form a valuable background for talks before the class or the science club. A few suggestions will enable you to make such posters and charts:

1. Make a poster illustrating all the animal groups. You will probably have to make the sketches free-hand, because it will be difficult to find pictures of Protozoa, cœlenterates, and such animals in newspapers or magazines.
2. On a map of the world, paste or draw pictures of the animals characteristic of certain regions. For example, put a buffalo on central North America, a lion on Africa, and a polar bear on Alaska.
3. Make a chart which will tell partly in pictures and partly in words the "Story of Coffee," for example, from the time the coffee plant first starts to grow until the coffee reaches your table. Almost any of the articles in everyday use will make good stories, as rubber, cork, cotton, wheat, silk, wool, or leather.
4. Make a chart which will show the life history of some animal, as the cabbage butterfly. Show the sort of environment in which each stage is spent.

There are many organizations which have pamphlets, bulletins, or other publications which may contain valuable material for a scrapbook. Some of these materials are sent without charge; for other material a small price is asked. The Superintendent of Documents, Washington, D. C., will send you, on request, price lists of the various bulletins published by the departments of the Federal government. Ask for lists of publications on "Fish," "Birds," "Forests," or any other subject in

which you are interested. From the Bureau of Biological Survey you can obtain lists of birds, information on bird-banding, and much other material related to bird habits. The United States Forest Service has a wealth of material you may have for the asking. It also has photographs which are sold to you at cost. Valuable national-parks pamphlets may be secured from the Bureau of National Parks, Department of the Interior, Washington, D. C.

Many motion pictures will be lent to your school at no cost except that of transportation. Write to the United States Department of Agriculture for a list of the subjects included.

You can secure much information from various state departments. The state Fish and Game Commission will answer questions regarding hunting laws, wild-life distribution, and problems of conservation. The state division of the Forest Service can give help on problems which relate to forestry and forest life. The various departments of your state university or other college or university will always coöperate by answering questions and giving advice.

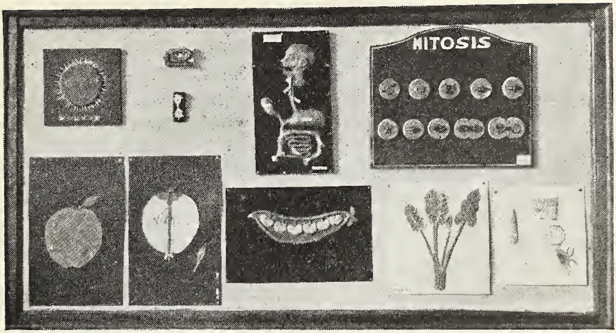
The American Nature Association, Washington, D. C., the National Wild Flower Preservation Society, Washington, D. C., and the National Association of Audubon Societies, New York City, are other sources of information.

If you like to draw. If you have ability to draw and if you enjoy drawing, try to make some large permanent wall charts for the biology laboratory or for your room at home. These may be either original sketches or copies of drawings in a textbook. Some which might be very useful are (1) grasshopper, (2) flower parts, (3) cross section of leaf, (4) life cycle of the tapeworm.

Charcoal or pencil sketches of trees in winter give good results even for the beginning artist. The bare branches against the sky show so well the habits of the tree that such a sketch is often a very satisfactory identification.

Cartoons not only are amusing, but help to illustrate a point in a way that is remembered. Try to make cartoons based upon such problems as conservation, forest-fire prevention, bird protection, conservation of wild flowers, the fight against insects, or the struggle for existence.

Make models. Perhaps you have seen in your laboratory or in a museum models of plants or animals or of some of their parts (Fig. 435). You can use plasticine or modeling clay to make excellent models. For example, try to make a model which will show the parts of a flower. You may use pieces of wood or wire to stiffen such parts as stem, pistil, and stamens. When all parts are put together to make the complete flower, support the model in a box or between blocks of wood until dry. Then paint the parts different colors.



Alfred F. Nixon

FIG. 435. Models made by high-school students. Can you suggest other good subjects?

Another kind of model might be that of the inside of a leaf. Use the top of a box such as a shallow shoe box as a support for your model until it dries. Make the separate cells by rolling and molding the clay to proper shape. Assemble them to look like Fig. 45, p. 75. You may color this model to make it more natural and attractive.

It is not difficult to make a good model of a protozoan such as the paramecium.

You can make good modeling material out of old newspapers. Soak them in water until they are soft. Then make a smooth pulp by rubbing the paper between the hands and forcing it through a sieve or screen.

Recreation with the microscope or hand lens. When you are collecting along a river or pond, bring in a small jar of mud from the bottom. Put the mud into a flat dish with water, and cover it. Let it stand a day or so. Then examine the water with a lens, or make slides and examine them with the low power of the microscope. How many kinds of animals do you find? If you consult a textbook or a reference book on fresh-water biology, you may be able to identify them as Protozoa, roundworms, earthworms, rotifers, and the like. But you will not be able to find exact names for every kind of animal. Do not expect your teacher to know what all these animals are. No teacher could know the thousands of possible kinds of animals you may find. The animals are fascinating to watch, even if it is impossible to name them all. Keep a record either in notes or in sketches of the interesting things you observe, as what and how the animal eats, how it moves around, and how it fights its enemies.

Keep this aquarium for a month or more, and examine it occasionally.

You will be surprised at the changes in animal life that take place. Animals that were abundant at one time may disappear, and others that you did not know were there will become most numerous.

Make an indoor garden. 1. Plant bulbs in a shallow dish filled with small rocks and coarse gravel, and fill the dish with water. Some of the best bulbs for this purpose are the paper-white narcissus, hyacinth, and calla lily.

2. Many kinds of plants will grow from cuttings, or slips. In the fall, before frost comes, look around your own yard and those of your neighbors for plants which can furnish material for the school greenhouse. Geraniums, begonias, Wandering Jew, and foliage plants (*Coleus*) are among the plants which grow readily from slips. Cut off the top of a branch, remove larger leaves, and place the slips in sand until they root. Then transplant them to flowerpots, window boxes, or hanging gardens.

3. Perhaps you have seen in a florist's window a large glass bowl or jar that contained a miniature garden. You can make a similar one easily. Use a bowl with flat sides by preference, such as a goldfish bowl. In the bottom put moist soil, sand, or peat moss. Then plant any small plants the tops of which do not come above the top of the bowl. Do not put in too many. Many small weeds are really beautiful. Moss used to carpet the surface adds much to the beauty of the garden. Put a piece of glass over the top of the bowl to prevent evaporation of water. This garden makes an attractive table centerpiece or a gift for a sickroom.

Terraria. Many interesting groups of plants and animals can be kept in the laboratory or at home. Bring in turtles, salamanders, toads, frogs, snakes, or lizards. Keep them in a cage where their environment is as natural as it is possible to make it. Use an aquarium or similar container or make a terrarium as follows: Secure a shallow wooden box about eighteen by twenty-four inches. Against each side, on the inside of the box, stand pieces of glass cut to fit into the box and about twelve inches high. Put in soil to the level of the top of the box. This soil will hold the glass in place at the bottom. To keep it from bulging, run a strip of tape around the outside of the glass pieces near the top. Make a glass cover to fit. You will of course have to vary the dimensions to suit the size of the living things you are going to keep.

A moist woodland terrarium should contain moss, small ferns, toads, salamanders, small woods turtles, snails, and any other forms of life characteristic of the woods where you collect. Keep the terrarium covered to prevent evaporation. If the animals are fed enough food, they should live through the winter in good condition. Occasionally take the cover off to permit airing out.

A bog terrarium may contain pitcher plants, sundew, dwarf cranberry, moss, frogs, salamanders, and other animals that you find in very

moist places. Remember that bog plants require acid soil. Therefore it is best to use only the soil in which you find the plants growing.

In very early spring bring pieces of soil in from the woods. Put them in a terrarium, water them well, and cover them. You will be surprised at the numbers of plants and animals that will appear.

Food for animal pets. The problem of obtaining food during the winter months for the lizards, frogs, and turtles that are kept in captivity is often difficult. Three types of food animals that are easily reared in large numbers are given:

The cockroach. Secure a pair of cockroaches, or a female carrying an egg case. Put them in a gallon battery jar or other wide-mouthed jar. In the bottom of the jar place a layer of sawdust. Cover the jar with a tightly fitting lid in which there are tiny holes to admit air, or tie a piece of cheesecloth over the top. A ring of vaseline just inside the jar will discourage attempts to crawl out. Put the jar in a warm dark place.

These insects will eat almost anything, though you will probably find that they prefer some foods to others. Try them with bread soaked in water, with some lettuce or cabbage. Keep a dish of water in the jar at all times.

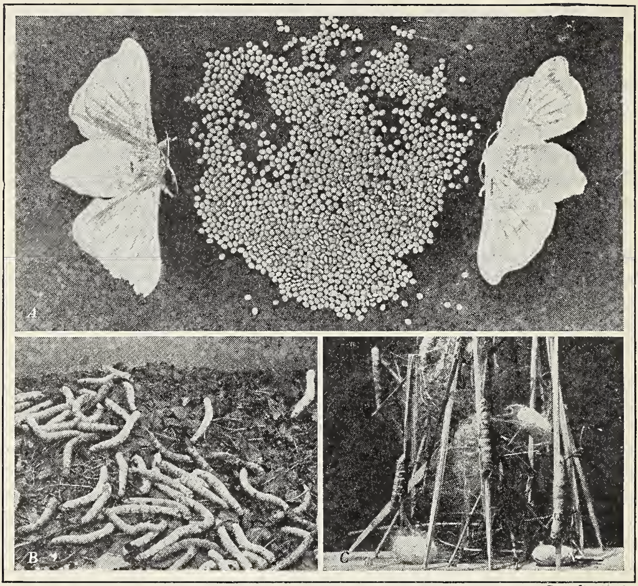
The female cockroach will carry the egg case around with her until the young are ready to hatch. Then she will hide it somewhere in the sawdust. The young will emerge by the next morning. Use care to see that none of the insects escape, because they are filthy pests in the house and once established it is extremely difficult to dispose of them. If the lizards or turtles do not eat the cockroach at once, it is better to remove the insect from the cage. Otherwise it will hide and escape into the building.

Mealworms. Such foods as oatmeal, flour, and corn meal sometimes become wormy. These "worms" are the larvæ of a beetle. They are excellent food for fish, frogs, and salamanders. Put some of the worms in a jar over which you tie a cloth. They will pupate, hatch, and lay eggs. You can soon have several jars in which the worms are in various stages of development, thus insuring a steady and plentiful supply of fish food.

Earthworms. Many of the smaller earthworms can be kept all winter in the laboratory with very little work. Secure a large wooden box about six inches deep. Bore a few holes in the bottom for drainage. First put in a layer of sand or gravel, and then fill the box with rich soil. Keep the soil moist but not wet. If the worms are dropped on top of the soil, they will soon burrow in. One can keep a great number of worms in one box if they are supplied with plenty of food. Among the foods they like best are pieces of lettuce and cabbage leaves. Do not be worried if the worms seem to pay no attention to the leaves until these are somewhat decayed. They like decayed leaves best.

Keeping insects in the classroom. In addition to the animals suggested in other parts of this chapter as suitable for keeping in the classroom, many insects are interesting to keep and observe.

Silkworms are very easy to raise and are intensely interesting to watch (Fig. 436). The commercial silkworm differs from our native cocoon-



Cornelia Clarke

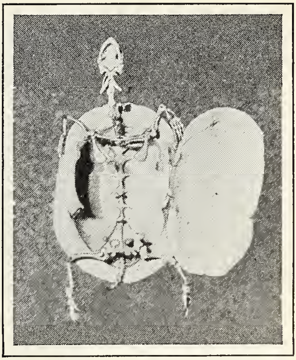
FIG. 436. Silkworms. *A*, adults and eggs; *B*, larvæ; *C*, larvæ and cocoons. In what sense is the silkworm a domesticated animal?

spinning moths in that it passes the winter in the egg stage rather than in a cocoon. As long as the eggs are kept cool they will not hatch. You must take advantage of this fact in planning your activities, for you do not want the worms to hatch before there are leaves to feed upon. The silkworm thrives best on the leaves of the mulberry, though it can be raised on Osage-orange leaves.

Order the eggs from a biological supply house in February or March, and keep them in a cool place or in the ice box until the mulberry leaves are almost out. The eggs will hatch in a week or ten days after they are brought into a warm room. Put them in a shoe box or similar container when you bring them into the room. As soon as the first tiny caterpillars appear, put two or three fairly large mulberry leaves into the box. They will not thrive on the tiny new leaves. It is well, too, to see that the leaves are not wet. If you keep a few fresh leaves in the box at all times, the caterpillars will not crawl away. It is therefore not necessary to cover

the box. As the worms get larger they will eat astonishingly large quantities of food. They feed for about a month before attaining their full growth. At that time they are ready to spin their cocoons. They become restless, eat very little, and will now wander away from the box. To prevent their straying, put into the box some twigs to which they can fasten the cocoons.

When the cocoons are completed remove them to an insect cage or a box covered with mosquito net or screen. In about two weeks the adults will emerge from the cocoons. Within a few days they will mate and lay eggs. Then they will die. The adult moths never eat. The female will lay the eggs on any surface. In order to make it easier to remove the eggs, stand pieces of cardboard along the sides of the cage, or paste flaps of paper to the box where the adults are kept. To keep the eggs from hatching, put them in a cool place.

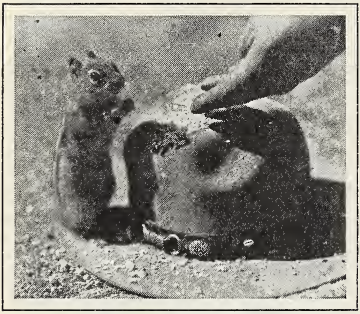


M. E. Van Ells

FIG. 437. This turtle skeleton was prepared and mounted by a high-school pupil in the manner here described. What values might one derive from preparing animal skeletons?

Mounting skeletons. The method here described for mounting a turtle skeleton would serve for mounting the skeleton of any small animal. Secure a medium-sized turtle and kill it with ether or in some other humane way which will not injure the skeleton. Saw through the lower shell at both sides and carefully remove the lower plate from the upper. Cut off as much flesh as possible without disturbing any of the bones. Place both plates in water which is slightly warm, and leave them there for a week or until the flesh has decayed sufficiently so that it slips easily from the bones. Carefully remove the flesh from the bones, taking care not to lose any of the bones. If you object to handling the decaying flesh with your bare hands, wear rubber gloves. As you remove the various bones, lay them together in the same relative positions that they had in the body. Be sure that the bones are entirely clean. If you experience difficulty in removing the last bit of flesh, put the bones into an aquarium with goldfish; the fish will quickly eat the small particles of flesh without injuring the skeleton. Mount the skeleton, using collodion or transparent lacquer to cement the bones together. Attach the bottom shell plate to the upper one in its original position, using small brass hinges. Mount the entire skeleton on a block of wood with a strong wire for support (Fig. 437).

After the mounted skeleton is thoroughly dry, cover the entire surface with a coat of lacquer; this will keep the skeleton clean and will enable you to dust it easily. In dusting it, use a camel's-hair brush in place of a dusting cloth.



U. S. Department of the Interior

Fig. 438. Feeding a chipmunk, Mount Lassen National Park, California. Do the relatives of this animal make equally good pets?

Keeping pets. Many wild animals make interesting pets both in captivity and in their native habitats (Fig. 438). Most of them can be kept alive and healthy in captivity. Of course, one must learn all he can about the habits of the animal in order to provide it with a suitable home and proper food. Remember that practically all wild animals need a place in which to hide. It is most cruel to keep them in open cages where they are exposed on all sides to possible enemies. But if they are cared for properly, there should be no possible objection to keeping them. There is every probability that most kinds of animals in captivity will live longer and more comfortably than in their native state. They are protected from enemies, and are supplied with abundant food without having to hunt for it.

Snakes frequently will not eat in captivity. One must therefore set them free after a week or so. Turtles, salamanders, toads, horned toads, and other lizards make interesting pets that are not at all hard to keep.

Reading for pleasure. There are so many excellent books written about plants and animals that it is difficult to make a list which will include everyone's favorites. The brief list which follows is made up of books that many boys and girls have found most interesting. You will often find other books by the same or by other authors which you may like even better.

Akeley, C. E., In Brightest Africa. Doubleday, Doran & Company, New York.

Beebe, William. The Arcturus Adventure. G. P. Putnam's Sons, New York.

Beebe, William. Beneath Tropic Seas. G. P. Putnam's Sons, New York. Also $1 edition, Blue Ribbon Books, New York.

Beebe, William. Jungle Days. G. P. Putnam's Sons, New York. Also $1, Garden City Publishing Company, Garden City, New York.

Chapman, W. G. Green Timber Trails. D. Appleton-Century Company, New York.

De Kruif, Paul. Hunger Fighters. Harcourt, Brace and Company, New York.

De Kruif, Paul. Men against Death. Harcourt, Brace and Company, New York.

De Kruif, Paul. Microbe Hunters. Harcourt, Brace and Company, New York.

Ditmars, R. L. Strange Animals I have Known. Brewer, Warren & Putnam, New York.

Dugmore, A. A. R. The Romance of the Beaver. J. B. Lippincott Company, Philadelphia.

Fabre, J. H. Insect Adventures. Dodd, Mead and Company, New York. Edited by Louise S. Hasbrouck. World Book Company, Yonkers-on-Hudson, New York.

Fishbein, Morris. Shattering Health Superstitions. Horace Liveright, New York.

Hornaday, W. T. Tales from Nature's Wonderlands. Charles Scribner's Sons, New York.

Johnson, M. E. Lion, African Adventures with the King of Beasts. Blue Ribbon Books, New York.

Lucas, F. A. Animals of the Past. American Museum of Natural History, New York.

Maeterlinck, M. The Life of the Bee. Dodd, Mead and Company, New York.

Mills, E. A. The Story of a Thousand-Year Pine. Houghton Mifflin Company, Boston.

Mills, E. A. Watched by Wild Animals. Doubleday, Doran & Company, New York.

Reed, W. M. The Earth for Sam. Harcourt, Brace and Company, New York.

Rolt-Wheeler, Francis. The Boy with the U. S. Naturalists. Lothrop, Lee & Shepard Co., Boston.

Scoville, Samuel, Jr. Everyday Adventures. Little, Brown & Company Boston.

Scoville, Samuel, Jr. Wild Folk. Little, Brown & Company, Boston.

Seton, E. T. Wild Animals I have Known. Charles Scribner's Sons, New York.

Sharp, D. L. The Face of the Fields. Houghton Mifflin Company, Boston.

Wheeler, W. M. Social Life among the Insects. Harcourt, Brace and Company, New York.

Among the reference books which you will find particularly useful in carrying out various projects in biology are the following:

Chapman, F. N. Color Key to North American Birds. D. Appleton-Century Company, New York.

Cowles, H. C., and Coulter, J. G. Spring Flora. American Book Company, New York.

Dickerson, M. C. The Frog Book. Doubleday, Doran & Company, New York.

Ditmars, R. L. The Reptile Book. Doubleday, Doran & Company, New York.

Forbush, E. H. Useful Birds and their Protection. State Board of Agriculture, Boston.

Holland, W. J. The Butterfly Book. Doubleday, Doran & Company, New York.

Howard, L. O. The Insect Book. Doubleday, Doran & Company, New York.

Jordan, D. S., and Everman, B. W. American Food and Game Fishes. Doubleday, Doran & Company, New York.

Keeler, H. L. Our Native Trees. Charles Scribner's Sons, New York.

Locy, W. A. Biology and its Makers. Henry Holt and Company, New York.

Lutz, F. E. The Field Book of Insects. G. P. Putnam's Sons, New York.

Mathews, F. S. The Book of Wild Flowers for Young People. G. P. Putnam's Sons, New York.

Mathews, F. S. Field Book of Wild Birds and their Music. G. P. Putnam's Sons, New York.

Morgan, Ann. Field Book of Ponds and Streams. G. P. Putnam's Sons, New York.

Reed, C. A. Bird Guide. Doubleday, Doran & Company, New York.

Rogers, J. E. The Tree Book. Doubleday, Doran & Company, New York.

Writing biology dramas. The history of biology, as found in textbooks, encyclopedias, and other sources, is full of incidents which can be made into plays to be presented in the biology classroom, in the school assembly, or in the science club. Suitable subjects for such plays are "The Conquest of Yellow Fever," "Overthrowing the Theory of Spontaneous Generation," "From Witch-doctor to Modern Medicine," and the like. You will often find it difficult to secure accurate information concerning the details of the incident. You will have to invent the conversation in most of your scenes. Make your stage directions as simple as possible. Here is a sample of this kind of play.

The Conquest of Hydrophobia

Revised from a Play Written by Donald Smith *and* Stella Arthur

SCENE I

Time: *About fifty years ago.* Place: Pasteur's *home in Paris*

Characters: Frau Meister *of Alsace, France; her son,* Joseph; Louis Pasteur

[*As the scene opens,* Pasteur *and* Frau Meister *are seated, and* Joseph *is standing by his mother, in* Pasteur's *living room.*]

Frau Meister. We have come to you, Monsieur, because you alone in all the world can save Joseph's life. We have heard of your great work, and have hurried without stopping until we reached your house.

PASTEUR. Is it the bite of a rabid dog, Madame, which has injured your son?

FRAU MEISTER. Yes, Monsieur. My brave Joseph was bitten by a mad dog when he kept the dog from biting the smaller children. He killed the dog, Monsieur, but not until it had bitten him fourteen times. We are terribly worried. So brave a boy should not die.

PASTEUR. My treatment for rabies has never been tried on any human being, but only on rabbits and dogs. I do not know whether it would cure Joseph, and I fear to try lest the treatment might not be successful.

FRAU MEISTER. Oh, but you must, Monsieur. It is the only chance to save my Joseph's life.

JOSEPH. You will give me the treatment, won't you, Monsieur Pasteur? You know I shall die if you do not help me.

PASTEUR. I may not have any right to try it. I fear you may die if I do.

JOSEPH. But that will not be your fault, Monsieur. I am willing to take that chance. I have no other chance to live.

FRAU MEISTER. Yes, Monsieur, I will take all the responsibility for the treatment; I will take all the blame in case the treatment is not successful. We hear that the men who work with you do not want you to treat a human being yet, but we cannot wait until they are ready. Joseph will die.

JOSEPH. You will do it, won't you, Monsieur?

PASTEUR. Yes, Joseph, I cannot refuse. I will give you the treatment. Come with me. [*Exeunt all three as the curtain falls.*]

SCENE II

TIME: *Two nights later.* PLACE: PASTEUR'S *study.*
CHARACTERS: PASTEUR, *a* PHYSICIAN, *and* MADAME PASTEUR

[*Present and seated are* PASTEUR *and a* PHYSICIAN.]

PHYSICIAN. The boy is sleeping quietly, is he not?

PASTEUR. Yes, yes. So very quietly. I fear he may be getting weaker.

PHYSICIAN. You gave him exactly the same doses you gave the dogs in the laboratory, did you not?

PASTEUR. You are right. At first, I gave him serum that had very weak rabies germs in it. And today I gave him a much stronger dose.

PHYSICIAN. Then tomorrow you will use serum that is even stronger?

PASTEUR. Yes, that is what I do with the dogs. For fourteen days I give them the serum, increasing its strength a little each day.

PHYSICIAN. Do the dogs always get well?

PASTEUR. Almost always. I do not understand exactly why, but they

do. I hope it will be the same with Joseph. I am so anxious that I can't sleep, and I can hardly think about anything else.

PHYSICIAN. I sincerely hope Joseph will get well. [*Rises and goes to the door.*] Good night, Monsieur Pasteur.

PASTEUR. Good night, Doctor.

[PASTEUR *seats himself at his study table staring straight ahead with a troubled expression. He rises and paces the floor. The door opens and* MADAME PASTEUR *appears in the doorway.*]

MADAME PASTEUR. Louis, it is so late, and you need rest and sleep so badly.

PASTEUR. I cannot sleep for worry about that boy Joseph. Suppose the treatment does not protect him, and he dies the awful death which rabies causes! It means so much if he gets well.

MADAME PASTEUR. He will not die.

PASTEUR. It is not as if I surely knew what to do. This is an experiment in which I have no choice but to use Joseph instead of a rabbit, a dog, or some other animal. Don't you see what it means?

MADAME PASTEUR. Oh yes, but you are doing your best, and better than anybody else in all the world could do.

PASTEUR. But my best may not be enough. I may fail to save the boy.

MADAME PASTEUR. You will not fail. God will not let you fail. But come now and rest. If you should yourself become ill, then nothing could save the boy.

PASTEUR. I will try to sleep soon, but I must think and plan for a while. Perhaps there is something more that I can do for Joseph, something which I have not yet thought of.

[MADAME PASTEUR *shakes her head sadly and closes the door as the curtain falls.*]

SCENE III

TIME: *Four weeks later.* PLACE: PASTEUR'S *living room.*

[PASTEUR, JOSEPH, *and* FRAU MEISTER *are seated.*]

PASTEUR. And how do you feel, Joseph?

JOSEPH. I am well, Monsieur, very well. The wounds made by that dog's teeth are now almost entirely healed, and I have no pain whatever.

PASTEUR. I think you are now out of danger, Joseph. There is no longer anything to fear. You are the first human being I have cured of rabies.

FRAU MEISTER. God bless you, Monsieur Pasteur. You have saved the life of my boy. We cannot thank you enough.

PASTEUR. And the way has been found to save many lives from one of the most terrible human dangers.

CURTAIN

GLOSSARY

A Suggestion. The following terms are important in the study of biology. The page number that is given is not the only page on which the word is used, but indicates the first point at which an additional explanation will be helpful. The wording of the explanation in the Glossary usually differs from that in the text but gives the same idea. If after reading the explanation in the Glossary you will turn to the text discussion and read it, you should then have a clear working idea of the proper use of the word.

abdomen (ab do′men): the part of the body including the chief digestive organs; the posterior part of the body of an insect, arachnid, or crustacean (p. 187).

acquired immunity: state of being immune through having had a disease or having been vaccinated (p. 440).

adaptation (ad ap ta′shun): that which fits an organism to live in its environment (p. 25).

adenoids (ad′e noidz): undesirable tissue growing on the back wall of the pharynx (p. 343).

adrenals (ad re′nalz): ductless glands located upon the kidneys (p. 363).

adventitious (ad ven tish′us): appearing out of their usual positions (p. 94).

algæ (al′je): the group which includes the simplest green plants (p. 36).

alimentary (al i men′ta ry) **canal:** the term which includes all organs through which food passes in digestion (p. 172).

alternation of generations: the condition in plants or animals in which the sexual and the asexual stage each produces the other, the two stages being necessary to complete the life cycle (p. 159).

altricial (al trish′al) **birds:** birds whose offspring are hatched in naked and helpless condition (p. 607).

alveoli (al ve′o li): air sacs in the lungs (p. 340).

amœboid (a me′boid): like an amœba (p. 308).

Amphibia (am fib′i a): the group of animals all of which have gills in early life, and most of which as adults develop lungs, such as frogs, toads, and salamanders (p. 214).

anabolism (an ab′o lizm): the processes concerned with building protoplasm from food (p. 49).

anatomy (a nat′o my): the study of the structure of living things (p. 7).

angiosperms (an′je o spurmz): the division of flowering plants the seeds of which develop in an ovary (p. 91).

Annelida (an nel′id a): the phylum of segmented worms, which

includes earthworms and sandworms (p. 175).

annual (an′u al): living for one year (p. 98).

antenna (an ten′na): a jointed appendage which bears sense organs and which appears on the head of such animals as insects and crustacea (p. 196).

anterior (an te′ri or): toward the head (p. 177).

anther (an′ther): the clublike tip of the stamen, in which pollen is formed (p. 144).

antibodies (an′ti bod iz): all the various substances which the cells manufacture as a means of combating disease germs (p. 439).

antiseptic (an ti sep′tik): a substance which kills or prevents the growth of bacteria, as tincture of iodine (p. 134).

antitoxin (an ti tox′in): a substance produced by the body to counteract the effects of toxins or poisons produced by germs (p. 439).

aorta (a or′ta): the artery, the largest in the body, which carries the blood from the left ventricle (p. 321).

appendages (a pen′da jez): the structures, usually jointed, which are attached to the body, as legs, arms, and tentacles (p. 186).

Arachnida (a rak′ni da): the class of arthropods to which spiders and ticks belong (p. 188).

artery (ar′ter y): a blood vessel leading away from the heart (p. 316).

Arthropoda (ar throp′o da): the phylum of animals, including insects, crustaceans, and spiders, which have exoskeletons and jointed appendages (p. 186).

asexual-spore reproduction: reproduction secured by spores that are not formed by union of cells (p. 561).

assimilation (a sim i la′shun): the process of changing digested food into living protoplasm (p. 305).

auricle (aw′ri kl): a chamber of the heart which receives blood from the veins (p. 211).

Aves (a′veez): the class of chordates which includes all birds (p. 124).

axillary (ax′i la ry): in the angle, as between the base of a leaf and the stem from which the leaf grew (p. 94).

bacteria (bak te′ri a), singular **bacterium** (bak te′ri um): the simplest and smallest plants; minute, one-celled fungus plants (p. 132)

balance of nature: condition in which the plants and animals of a region maintain relatively unchanging numbers (p. 28).

biennial (bi en′i al): a plant which lives for two years, storing food the first year and producing seeds the second (p. 111).

bilateral symmetry: having two halves exactly alike, as the halves of the body, which completely match each other (p. 165).

blastula (blas′tu la): the stage of development of an animal em-

bryo in which it resembles a hollow ball (p. 592).

botany: the study of plants (p. 7).

bronchi (bron'ki): the two large branches of the trachea or windpipe which lead to the lungs (p. 343).

Bryophyta (bri of'i ta): the phylum of plants which includes mosses and liverworts (p. 138).

budding: a form of asexual reproduction (p. 564); a method of grafting (p. 562).

bug: an insect (order Hemiptera) which has sucking mouth parts, and wings of which the front portion is opaque and the rear portion transparent. Examples are bedbug, squash bug, and stinkbug (p. 197).

Calorie (kal'o ry): the amount of heat used in raising the temperature of one kilogram of water one degree centigrade (p. 263).

calyx (ka'lix): the outer part of a flower, usually green; the sepals (p. 143).

cambium (kam'bi um): the growing tissue between the xylem and the phloëm in the vascular bundles (p. 92).

capillaries (kap'i la riz): the minute blood vessels which connect the arteries and veins (p. 314).

carapace (kar'a pase): the hard covering on the dorsal surface of crustacea and turtles (p. 191).

carbohydrates (kar bo hy'drates): food substances, including sugars and starches, which contain carbon, hydrogen, and oxygen in certain proportions (p. 81).

carbon dioxide: a gas composed of one part of carbon and two parts of oxygen (p. 37).

carnivorous (kar niv'o rus): eating the flesh of animals (p. 128).

cartilage (kar'ti laj): a tough elastic animal tissue; gristle (p. 209).

catabolism (ka tab'o lizm): the processes involved in breaking up living cells (p. 49).

cell: one of the units of protoplasm of which all living things are composed; it consists of a nucleus in a mass of cytoplasm, which is usually inclosed within a cell wall (p. 50).

cellulose (sel'u los): the material of which plant cell walls are chiefly composed (p. 52).

cephalothorax (sef a lo tho'rax): the combined head and thorax, as in crustacea (p. 192).

cerebellum (ser e bel'um): the part of the brain which coördinates movement (p. 219).

cerebrum (ser'e brum): the large part of the brain occupying the upper part of the skull, controlling voluntary movement and, in man, the thought processes (p. 219).

character (kar'ak ter): in its biological use a character is one of the principal features or qualities of a living thing, as the color, size, form, or structure of its parts (p. 613).

chitin (ki'tin): the horny, elastic material composing the exoskeletons of Arthropods (p. 195).

chlorophyll (klo'ro fil): the green coloring matter of plants (p. 7).

chloroplast (klo'ro plast): the structure in a plant cell which contains chlorophyll (p. 75).

Chordata (kor da'ta): the phylum which includes all animals with a spinal cord (p. 124).

chromatin (kro'ma tin): the essential substance of chromosomes and nuclei; so called because it is readily seen in color when dyes are applied to the cells (p. 621).

chromosomes (kro'mo somes): bands or rods made from the chromatin; the chief structures involved in mitosis; the carriers of hereditary characters (p. 621).

chrysalis (kris'a lis): the dormant form of certain insects, in which the pupa is inclosed in a thin hard shell (p. 33).

cilia (sil'e a), *singular* **cilium**: hairlike projections of protoplasm from the surface of a cell, which by their movements cause the cell to move or produce movement in the surrounding liquid (p. 152).

circulatory system: the system of vessels by means of which the blood or sap is carried through all parts of the body of the animal or plant (p. 307).

clitellum (kli tel'um): a thick glandlike region of the body of annelids, used in making the cocoon (p. 288).

cloaca (klo a'ka): the tube, in such chordates as the frog and bird, through which digestive wastes, urinary wastes, and reproductive cells all pass from the body (p. 219).

cocoon (ko koon'): the silken case which is spun by certain insect larvæ and in which the pupa develops; a somewhat similar case is made by spiders and earthworms to inclose the eggs (p. 200).

Cœlenterata (se len ter a'ta): a phylum of animals which contains the corals, sea anemones, jellyfish, and fresh-water hydras (p. 160).

communicable diseases: diseases which may be transmitted from one person to another (p. 427).

complete flower: one having all parts, as petals, sepals, stamens, and pistil (p. 581).

Compositæ (kom poz'i tee): the name of the most complex group of flowering plants — such as the dandelion and sunflower (p. 148).

conifers (kon'i furz): the cone-bearing plants (p. 143).

conjugation (kon ju ga'shun): the process of union of similar gametes (p. 577).

contractile vacuole (con trak'til vak'u ole): a bubble-like reservoir in the protoplasm of a protozoan in which waste products are collected before being expelled from the cell (p. 350).

corolla (ko rol'a): one of the outer groups of specialized parts of a flower, usually colored; the petals (p. 143).

corpuscles (kor'pus lz): small bodies, such as the cells in the blood (p. 314).

cortex (kor'tex): the outer protecting layers of roots and

stems; also the outer layers of such organs as the brain or kidney; bark (p. 92)

cotyledon (kot i le′don): one of the seed leaves of a plant embryo (p. 91).

Crustacea (krus ta′she a): the class of Arthropods including crayfish and lobsters (p. 187).

culture (kul′chure): cultivation of microscopic living things such as bacteria, yeasts, and Protozoa (p. 444).

cyst (sist): a group of cells, or a small organism, usually dormant, inclosed within a firm wall (p. 152).

cytoplasm (si′to plazm): all of the protoplasm within a cell except the nucleus (p. 52).

deciduous (de sid′u us): falling off at maturity, as the leaves of certain trees, first teeth, and antlers (p. 72).

diaphragm (di′a fram): the dome-like sheet of muscle separating the lung cavity from the abdominal cavity in mammals; used in breathing (p. 344).

diastase (di′as tase): an enzyme in germinating seeds, saliva, and pancreatic juice; changes starch into sugar (p. 286).

dicotyledon (di kot i le′don): a plant having two seed leaves, belonging to one of the two divisions of the angiosperms (p. 91).

diffusion (de fu′zhun): the process by which molecules of liquids or gases or both mingle by their own movements (p. 67).

digestion (di jes′chun): the processes by which foods are changed to certain liquids, which can be absorbed and used by cells (p. 21).

dinosaur (di′no sawr): an extinct reptile (p. 220).

dividing spindle: the name applied to the nucleus and the attached cytoplasm in the stage in which the chromosomes are being separated to form new nuclei (p. 622).

division of labor: separation of work into different kinds to be done by special parts of a plant or animal (p. 17).

dormant (dor′mant): inactive or resting for a long period (p. 73).

dorsal (dor′sal): having to do with the back (p. 176).

Echinodermata (e ki no der ma′ta): a phylum of animals with spiny coverings which usually are shell-like or are shells; examples are starfish and sea urchins (p. 173).

ectoderm (ek′to derm): the outer layer of cells in an early stage of the embryo of animals or in a simple animal, as *Hydra* (p. 162).

elimination (e lim i na′shun): the process of removal of waste substances (p. 175).

embryo (em′bre o): the plant or animal in its earliest stages of development (p. 91).

encyst (en sist′): to inclose in a cyst (p. 169).

endocrine (en′do krine) **glands**: ductless glands; they secrete hormones directly into the blood (p. 358).

endoderm (en'do durm): inner layer of cells in an early stage of the embryo of animals or in a simple animal, as *Hydra* (p. 162).

endosperm (en'do spurm): special food-storage tissue within plant seeds (p. 145).

energy (en'er jy): the capacity to do work (p. 4).

entomologist (en to mol' o jist): a scientist who studies insects (p. 194).

environment (en vi'run ment): the surroundings; all the factors within the habitat (p. 12).

enzyme (en'zime): an organic substance which causes such chemical changes as those of digestion or fermentation, without itself changing (p. 284).

epidermis (ep i dur'mis): the outside tissue covering the bodies of plants and animals (p. 74).

epiglottis (ep i glot'is): the tissue which closes the windpipe when anything is swallowed (p. 343).

epiphyte (ep'i fite): a plant which grows upon another for support (p. 117).

esophagus (e sof'a gus): the portion of the alimentary canal leading from the throat to the stomach; the gullet (p. 294).

Eustachian (u sta'ke an) **tube**: the tube which leads from the middle ear to the throat (p. 417).

exoskeleton (ex o skel'e tun): the hard outside covering of such animals as insects and crustaceans (p. 24).

extinct (ex tinkt'): no longer to be found living on the earth (p. 209).

fats: one of the groups of energy foods (p. 262).

feces (fe'seez): the intestinal wastes of animals; the excrement (p. 171).

fermentation (fur men ta'shun): the process by which yeasts and bacteria act upon foods containing sugar to produce alcohol and carbon dioxide (p. 136).

fertilization (fur til i za'shun): the process in reproduction by which the sperm unites with the egg (p. 583).

fibrinogen (fi brin'o jen): the material within the blood which when exposed to air forms the threadlike fibers of the clot (p. 326).

fibrovascular bundles: *see* vascular bundles.

filament (fil'a ment): a fine thread (p. 136).

filterable virus (vi'rus): a disease-producing organism or its products which are so small that they can pass through laboratory filters (p. 559).

fission (fish'un): the process of asexual reproduction by which cells divide into two equal parts (p. 562).

flagella (fla jel'a), *singular* **flagellum**: hairlike extensions of protoplasm similar to cilia but usually longer and less numerous (p. 155).

fossil (fos'il): the preserved form or other evidence of an animal or plant that lived ages ago (p. 38).

fruit: the ripened ovary and its contents and sometimes other

structures that ripen with it (p. 144).

fungus (fun'gus), *plural* **fungi** (fun'ji): the group name for simple plants that do not have chlorophyll (p. 129).

gall bladder: the sac in which bile from the liver is stored (p. 219).

gametes (gam'eets): the sex cells which may unite to form spores (p. 579).

gametophyte (ga me'to fite): the sexual stage in the alternation of generations of plants (p. 596).

ganglion (gang'gli on): a mass or group of nerve cells (p. 288).

gastric (gas'tric): pertaining to the stomach, as gastric juice (p. 295).

gastrula (gas'tru la): the stage in the development of an animal embryo in which a portion of the wall is folded inward, giving the animal a cuplike shape (p. 592).

genes (jeenz): the elements or units in the chromosomes of cells; each one is supposed to be responsible for carrying certain hereditary characters (p. 623).

geotropism (je ot'ro pizm): tendency of organs to be attracted toward the earth, as roots (p. 372).

germination (jur mi na'shun): the process of starting growth, as of the embryo plant from the seed (p. 583).

gizzard (giz'ard): a muscular digestive organ of birds and some lower animals which grinds up the food (p. 177).

glycogen (gli'ko jen): a form of carbohydrate known as animal starch, stored chiefly in the liver (p. 267).

grafting: the process of inserting a branch or scion upon another organism so as to make it grow as part of that organism (p. 571).

guard cells: the cells which regulate the size of a stoma (p. 74).

gymnosperms (jim'no spurmz): the group of seed plants of which the ovules are exposed, as pines and firs (p. 90).

habitat (hab'i tat): the region in which a plant or animal lives (p. 24).

hemoglobin (he mo glo'bin): the iron compound in the red blood corpuscles, which carries oxygen and carbon dioxide (p. 325).

hereditary (he red'i ta ry): transmitted from parents to their offspring (p. 620).

hermaphroditic (her maf ro dit'ik): possessing both male and female reproductive structures (p. 584).

hibernate (hi'ber nate): to pass the winter in a dormant condition (p. 201).

hilum (hi'lum): the small mark or scar on a seed, showing where it was attached to the pod (p. 144).

homologous (ho mol'o gus): similar in structure or in location on the body (p. 212).

hormone (hor'mone): the chemical product of a ductless gland which affects the development or functioning of some other part of the body (p. 308).

host: the organism on or in which a parasite lives (p. 104).

humus (hu'mus): organic matter in the soil resulting from decay (p. 491).

hybrid (hi'brid): the offspring of two parents which are considerably unlike in some of their hereditary characters (p. 618).

hydrotropism (hi drot'ro pizm): tendency of organs to be attracted toward water (p. 372).

hygiene (hi'ji een): the study of the conditions affecting health for the purpose of promoting its improvement (p. 465).

hypocotyl (hi po kot'il): the part of an embryo plant below the seed leaves, most of which develops into the root (p. 145).

imbibition (im bi bish'un): the rise of water in dead cells and in the microscopic pores and spaces in cell walls (p. 85).

immunity (i mu'ni ty): the condition in which an organism is able to resist the attacks of disease (p. 438).

incubation (in ku ba'shun): the process of maintaining proper conditions of heat and moisture for developing animals within the egg covering (p. 601).

infest (in fest'): to enter or take possession in such numbers as to threaten the life or welfare of other organisms (p. 166).

infusion (in fu'zhun): a nourishing liquid, made by steeping organic material in water, in which microscopic organisms are grown (p. 557).

inheritance (in her'i tance): the reception of characteristics from ancestors (p. 552).

inoculation (in ok u la'shun): act of infecting with microscopic forms (p. 441).

inorganic matter: matter which is not and has never been a living thing, or its products (p. 63).

insulin (in'su lin): a hormone secreted by certain cells in the pancreas; a remedy, containing this hormone, used in the treatment of diabetes (p. 364).

intestine (in tes'tin): part of the food canal following the stomach (p. 288).

invertebrates (in ver'te brates): animals that do not possess internal skeletons (p. 155).

involuntary (in vol'un ta ry): not directed by the will or not under the control of the will (p. 385).

irritability (ir i ta bil'i ty): the capacity for responding or reacting to stimuli (p. 49).

kidney (kid'ny): a highly specialized organ of excretion which removes waste products, chiefly water and urea, from the blood (p. 351).

lacteals (lak'te alz): the lymphatic vessels in the villi, into which digested fats pass (p. 327).

larva (lar'va), *plural* **larvæ** (lar'vee): the wormlike stage of certain insects (p. 27).

leguminous (le gu'mi nus): of the nature of legumes (a group of pod-bearing plants such as bean, pea, alfalfa, and clover) (p. 493).

lenticel (len′ti sel): a small opening in bark, through which gases may pass (p. 325).

life cycle (life history): all the different stages of development through which an organism passes (p. 166).

lipase (lip′ase): an enzyme which digests fats (p. 286).

liver: the largest gland; it secretes bile, stores glycogen, and produces important changes in the blood (p. 219).

liverworts (liv′er wurts): usually flat green plants which with the mosses compose the phylum Bryophyta (p. 38).

locomotion (lo ko mo′shun): act of moving from place to place (p. 21).

lymph (limf): the fluid which surrounds the cells. It is composed of plasma which has escaped from the capillaries (p. 316).

lymphatic (lim fat′ik): a tube which carries lymph (p. 316).

lymphatic system: all the lymph glands and the vessels through which lymph passes on its way back into the circulatory system (p. 317).

Malpighian (mal pig′i an) **tubes:** excretory organs of insects which remove from the blood waste products, chiefly water and urea, and discharge them into the intestine (p. 289).

mammal: one of the highest group of chordates, which feeds its young on milk secreted by milk glands (or mammary (mam′a ry) glands) (p. 234).

mandibles (man′di blz): the biting mouth parts of insects or crustaceans (p. 255).

marsupials (mar su′pi alz): mammals having a special pouch for carrying their young (p. 241).

maxilliped (max il′i ped): one of the leglike mouth parts of crustaceans (p. 192).

medulla (me dul′a): the posterior region of the brain which controls such involuntary movements as those of breathing and heartbeat (p. 384).

medullary (med′u la ry) **rays (p. 97):** *see* pith ray.

mesentery (mes′en ter y): the membranes which surround the intestines and support them from the dorsal walls of the abdomen (p. 219).

metabolism (me tab′o lizm): the processes related to building up (anabolism) and breaking down (catabolism) the living parts of plants and animals (p. 49).

metamorphosis (met a mor′fo sis): the changes in form which an animal undergoes in developing to the adult stage (p. 156).

Metazoa (met a zo′a): collective name for all animals consisting of more than one cell (p. 154).

micropyle (mi′kro pile): the small opening in an ovule through which the pollen tube usually enters (p. 145).

midrib (mid′rib): the central vein of a leaf (p. 76).

mitosis (mi to′sis): the entire process of cell division through formation of chromosomes, their

division, and the formation of new cells (p. 621).

molds: a group of small fungus plants (p. 136).

Mollusca (mo lus'ka): the phylum of animals which have soft bodies, usually inclosed in a shell (p. 178).

molt: to shed feathers, skin, or other covering (p. 193).

monocotyledon (mon o kot i le'-don): a plant with one seed leaf, belonging to one of the two divisions of the angiosperms (p. 91).

mucus (mu'kus): a substance, secreted by small glands, which makes slippery the walls of the digestive and respiratory systems (p. 294).

mutant (mu'tant): a plant or animal which possesses and transmits to its offspring any distinctly changed character (p. 616).

mutation (mu ta'shun): a heritable modification of a distinct character (p. 616).

Myriapoda (mir i ap'o da): the class of Arthropods distinguished by many pairs of legs (p. 189).

narcotic (nar kot'ik): any substance which produces stupor or sleep and which dulls the senses (p. 322).

natural immunity (i mu'ni ty): the ability to resist a disease because of inherited characters, general health, or age (p. 439).

neuron (nu'ron): a nerve cell (p. 373).

nictitating (nik'ti ta ting) **membrane**: the third eyelid of certain animals, as birds and turtles, also present but incomplete in some of the higher animals (p. 229).

non-energy foods: all foods except carbohydrates, proteins, and fats (p. 273).

notochord (no'to kord): the rod of cartilage which supports the nerve cord in the lowest chordates (p. 208).

nucleus (nu'kle us): the small, dense mass of protoplasm within a cell which controls cell activities and cell division; it contains the bodies which transmit hereditary characters (p. 52).

nutrition (nu trish'un): the term which includes all processes concerned with the utilization of food by living organisms (p. 49).

nymph (nimf): the immature form of an insect that undergoes an incomplete metamorphosis (p. 201).

olfactory (ol fak'to ry): pertaining to the sense of smell (p. 383).

omnivorous (om niv'o rus): feeding on both plants and animals (p. 260).

operculum (o per'ku lum): a fold or plate of tissue such as that covering the gills of a young tadpole (p. 216).

optic (op'tik): pertaining to the sense of sight (p. 383).

organ (or'gan): a group of tissues which together perform some special function (p. 53).

organic (or gan′ik) **matter**: matter which is a part of or a product of an organism (p. 63).

organism (or′gan izm): any living thing (p. 63).

osmosis (os mo′sis): the passing of liquids or gases through cell walls or other membranes from places of higher concentration to those of lower concentration (p. 67).

osmotic (os mot′ik) **pressure**: the pressure which is caused by the unequal concentration of solutions separated by a membrane, and which results in osmosis (p. 86).

ovary (o′va ry): in plants, the part of the pistil within which ovules are formed; in animals, one of the structures in which the eggs are formed (p. 582).

ovipositor (o vi poz′i ter): the egg-laying organ which enables certain insects, as the grasshopper and the ichneumon fly, to pierce such substances as earth or epidermis to deposit eggs (p. 196).

ovule (o′vule): the structure within the ovary in which the embryo develops (p. 582).

oxidation (ox i da′shun): the process in which oxygen combines with another substance, releasing energy (p. 65).

palisade (pal i sade′) **tissue**: elongated green cells in the leaf arranged in parallel rows, usually beneath the upper epidermis (p. 75).

pancreas (pan′kre as): a highly specialized gland which produces several digestive enzymes and the hormone insulin (p. 298).

parasite (pair′a site): an animal or plant which secures its nourishment at the expense of a living plant or animal (p. 19).

pelvis (pel′vis): the bony basin which upholds the abdominal organs of many of the vertebrates (p. 237).

perfect flower: a flower which has stamens and pistil but may lack petals and sepals (p. 581).

pericardium (per i kar′di um): the membrane surrounding the heart (p. 319).

periosteum (per i os′te um): the outer tissue of the bone (p. 238).

phloëm (flo′em): the outer region of the vascular bundle through which sap descends (p. 92).

photosynthesis (fo to sin′the sis): the process by which chlorophyll, using the sun's energy, manufactures carbohydrates from carbon dioxide and water, and releases oxygen (p. 83).

phylum (fi′lum), *plural* **phyla**: the major divisions of the plant or the animal kingdom (p. 125).

physiology (fiz i ol′ o jy): study of living processes of plants and animals (p. 7).

Pisces (pis′eez): the class of chordates which includes all fishes (p. 123).

pistil (pis′til): the central part of a flower, consisting of ovary, style, and stigma, which produces the female reproductive cells (p. 144).

pistillate cone: the collection of structures on which ovules are

borne in the cone-bearing plants (p. 143).

pith: the spongy tissue in stems and branches, usually composed of large thin-walled cells (p. 93).

pith rays: tissues radiating from the center toward the outside of stems and carrying water and food horizontally to cells not served directly by xylem and phloëm (p. 94).

placenta (pla sen'ta): the vascular tissue which attaches a developing embryo to the parent, and through which the embryo secures food and oxygen (p. 588).

plasma (plaz'ma): the liquid part of the blood (p. 317).

plumule (plu'mule): the leaves and stem of an embryo plant (p. 145).

pollen (pol'en): the small sexual spores of plants from which the male cells develop (p. 144).

Porifera (po rif'er a): the phylum of porous animals to which the sponges belong (p. 154).

precocial (pre ko'shal) **birds**: birds whose offspring when hatched are covered with down and can pick up and swallow their food (p. 607).

Primates (pri ma'tez): the highest class of chordates, that to which man belongs (p. 241); **primate** (pri'mate; *plural pronounced* pri'mates): an individual member or (*plural*) members of the class.

propagation (prop a ga'shun): reproduction, especially as used in oyster farming (p. 181).

protective (pro tek'tiv) **colorations**: body colors which blend with the surroundings, with the result that the animal is hard to see (p. 197).

protective resemblance: such a similarity to other objects in color, form, or habit as assists the animal to survive (p. 197).

proteins (pro'te inz): complex energy foods containing nitrogen and other elements in addition to carbon, hydrogen and oxygen (p. 82).

protonema (pro to ne'ma): the early stage of mosses, which is produced by the asexual spores (p. 594).

protoplasm (pro'to plazm): the living substance of the cell (p. 48).

Protozoa (pro to zo'a): the phylum which includes the one-celled animals (p. 150).

pruning: cutting away some parts so that later growth may be improved (p. 115).

Pteridophyta (ter i dof'it a): the phylum of plants which includes the ferns, club mosses, and horsetails (p. 140).

quarantine (kwor'an teen): a law for compelling plants, animals, or people having or suspected of having an infectious disease to remain away from others until danger of spread of the disease has passed (p. 430).

radial (ra'di al) **symmetry**: the arrangement of structures of an organism by which the major parts radiate from the center, as

in the starfish, or leaves of a moss plant (p. 160).

recessive (re ses'siv) **character:** a character which is obscured in offspring by a dominant character, but which can be transmitted to a later generation (p. 624).

reflex (re'fleks) **actions:** bodily actions controlled by spinal nerve centers without conscious direction from the brain (p. 375).

reflex arc: all the sensory and motor nerves involved in producing a reflex action (p. 385).

regeneration (re jen er a'shun): act of replacing an injured or missing part or parts (p. 567).

reproduction (re pro duk'shun): the process of producing new living things (p. 561).

Reptilia (rep til'i a): the class of chordates which includes snakes, lizards, and alligators (p. 123).

respiration (res pi ra'shun): the process by which an organism takes in oxygen and gives off carbon dioxide (p. 49).

rhizoids (ri'zoids): rootlike outgrowths, as the hairlike growths at the lower ends of moss stems (p. 139).

rhizome (ri'zome): a stem which grows in the soil like a root (p. 141).

Rodentia (ro den'she a): the order of mammals which includes the gnawing animals, as rabbits and mice (p. 123).

rudimentary (ru di men'ta ry): imperfectly developed (p. 310).

rusts: a group of parasitic fungi which produce serious diseases in certain higher plants (p. 129).

saprophyte (sap'ro fite): a plant which secures its nourishment from the dead and decaying bodies of other plants and animals (p. 19).

scavenger (skav'en jer): any animal that eats refuse or decaying matter (p. 194).

scion (si'un): a branch or cutting from which new growth may be produced (p. 572).

secrete (se krete'): to produce special liquids, as the products of glands (p. 87).

secretion (se kre'shun): the process by which a gland produces a liquid substance, as a hormone or an enzyme; the product of a gland (p. 87).

seedling (seed'ling): a young plant which has recently developed from a seed (p. 101).

segment (seg'ment): one of the ringlike divisions composing the body of such an animal as an annelid; arthropods and chordates are also segmented animals (p. 166).

semicircular canals: the canals in the bony part of the ear which constitute the organ of equilibrium (p. 417).

sensory neuron (nu'ron): a nerve fiber over which impulses are carried from a stimulated area toward the brain or spinal cord (p. 374).

serum (se'rum): the clear yellowish liquid which remains when blood clots (p. 326); a substance injected into the blood in the treatment or prevention of certain diseases (p. 449).

skeleton (skel′e tun): the supporting or protecting structures of an organism (p. 155).

spermatophytes (sper mat′o fites): plants of the phylum Spermatophyta, which includes all seed plants (p. 143).

sperms: the male reproductive cells of plants and animals (p. 580).

spiracle (spir′a kl): an opening into the body for breathing, as in insects and tadpoles (p. 339).

spleen: an abdominal organ commonly thought to be a ductless gland but the function of which is not definitely known (p. 219).

spongy tissue: loosely arranged chlorophyll cells of the leaf (p. 75); the less compact tissues of the bones (p. 238).

spontaneous generation (spon ta′ne us jen er a′shun): the theory that living things can be produced from nonliving things (p. 553).

sporangium (spor an′ji um), *plural* **sporangia**: the cell or case in which asexual spores are produced (p. 597).

spore: a specialized cell capable of developing into the living thing that produced the spore (p. 137).

sporophyte (spo′ro fite): the asexual stage in the alternation of generations of plants (p. 596).

stamen (sta′men): the part of a flower which bears the pollen (p. 147).

staminate (stam′i nate) **cone**: a cone which produces pollen only (p. 143).

sterilize (ster′i lize): to destroy all germs within or upon a substance (p. 435); to make reproduction impossible (p. 324).

stigma: the tip of the pistil (p. 144).

stimulus (stim′u lus): that which produces or arouses action or response (p. 49).

stolon (sto′lon): a branch or runner from which new plants may develop (p. 568).

stoma (sto′ma), *plural* **stomata** (sto′ma ta): openings in leaves or stems through which gases enter and leave the plant (p. 74).

swimmerets (swim′mer ets): appendages on the abdomen of a crustacean which aid in swimming, in reproduction, and, indirectly, in respiration (p. 192).

symbiosis (sim bi o′sis): a partnership of two or more totally different organisms, in which each contributes something to the other or others (p. 44).

system of classification: the plan or scheme by which living things are grouped and named according to relationship in structure and habit (p. 122).

tendon (ten′dun): the tough cord or band which attaches a muscle to a bone (p. 218).

tendril (ten′dril): a slender and winding growth serving to attach a climbing plant to its support (p. 115).

tentacles (ten′ta klz): flexible appendages which may aid such animals as *Hydra* and the octopus in food-getting, in locomo-

tion, or in various ways as sense organs (p. 161).

testes (tes′teez): male sex glands in which sperms are produced (p. 585).

Thallophyta (thal of′it a): the lowest phylum of plants, including the algæ and fungi (p. 129).

thorax (tho′rax): the middle division of an insect's body, to which the legs are attached (p. 196); in higher animals, the part of the body between the abdomen and the neck (p. 194).

tissue (tish′u): a group of cells of the same kind, serving the same function (p. 53).

toxin (tox′in): a poisonous protein formed by disease-producing germs (p. 439).

trachea (tra′ke a): in higher animals, the air passage leading from the throat to the lungs (p. 294); in insects, one of the air tubes (p. 294).

transpiration (tran spi ra′shun): the process of evaporating water into the air from plants (p. 84).

trichinosis (trik′i no′sis): a disease produced by a small roundworm (p. 172).

tropism (tro′pizm): the simplest reaction to a stimulus (p. 371).

tubercles: small rounded structures projecting from a surface, as the nodules on roots of clover, beans, etc. in which nitrogen-fixing bacteria grow (p. 493).

tympanic (tim pan′ik) **membrane**: the tightly stretched membrane which by vibrating produces the sensation of hearing; in higher animals, the eardrum (p. 417).

ungulates (ung′gu lates): hoofed mammals (p. 241).

unit character: a character or quality which is inherited independently of other characters (p. 627).

urea (u re′a): a nitrogenous waste product resulting from metabolism, and excreted in the urine of higher animals (p. 348).

urinary bladder: the sac in which urine is collected (p. 352).

vaccination (vak si na′shun): the introduction into an animal of dead or weakened germs or their products, as a means of inducing immunity (p. 451).

vacuole (vak′u ole): a space in a cell filled with gas, food in process of digestion, or liquid excretions (p. 52).

variation (va ri a′shun): deviation in structure or function from the parent (p. 613).

vascular bundles: bundles of elongated cells which function in transporting liquids in plants (p. 76).

vascular tissue: tissue consisting largely of tubes conveying liquid.

vegetative reproduction: production of new individuals directly from a growing, or vegetative, part of an organism (p. 561).

veins: the blood vessels through which blood returns to the heart (p. 314).

ventral (ven′tral): pertaining to the lower, or abdominal, side of the body (p. 191).

ventricle (ven′tri kl): the cham-

ber of a heart from which the blood is forced into an artery (p. 319).

vertebra (ver'te bra): one of the segments of the backbone, or spinal column (p. 208).

vertebrate (ver'te brate): one of the group of chordates which has a bony spinal column serving as the main support of the body (p. 206).

villi (vil'i): small projections from the walls of the small intestine which serve to absorb food into the blood stream (p. 301).

vitamin (vi'ta min): one of a group of non-energy foods necessary to health and normal development (p. 273).

xylem (zi'lem): the inner region of a vascular bundle, containing hard, woody tissue and cells for transporting liquids upward (p. 92).

yeasts: a group of fungus plants (p. 135).

zoology (zo ol'o jy): study of animals (p. 7).

zoospore (zo'o spor): an asexual spore which can swim (p. 566).

zygospore (zi'go spor): the sex spore formed by union of similar gametes (p. 578).

INDEX

[Illustrations are indicated by asterisks after page numbers. When an asterisk precedes the first number of a group of pages, it means that several illustrations are included.]